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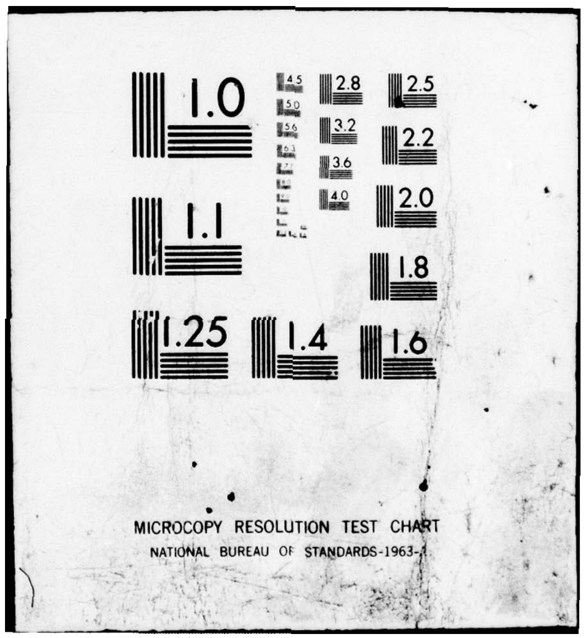
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NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

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ANNAPOLIS DIVISION - ANNAPOLIS, MARYLAND 21402

Status Report, Fiscal Year 1968
Deep Ocean Technology Program

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August 1968

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Status Report, Fiscal Year 1968, Deep Ocean Technology Program

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The Naval Ship Research and Development Center is a U.S. Navy center for laboratory effort directed at achieving improved sea and air vehicles. It was formed in March 1967 by merging the David Taylor Model Basin at Carderock, Maryland and the Marine Engineering Laboratory at Annapolis, Maryland.

Naval Ship Research and Development Center
Washington, D.C. 20007

NDW-NSRDC 3960/46 (10-67)

6 **Deep Ocean Technology Program. Status Report, Fiscal Year 1968,**

Status Report
Deep Ocean Technology

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ABSTRACT

This report presents the status of certain deep ocean technology projects related to submersible electric machinery systems and the tandem propulsion system for deep submergence vehicles.

ACKNOWLEDGMENTS

This report was coordinated and distributed by the Annapolis Division, Naval Ship Research and Development Center, at the request of the Deep Ocean Technology Submersible Vehicles Program Manager, Naval Ship Systems Command (SHIPS 0324). The technical information was prepared by the following project engineers:

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From: Cfficer in Charge
To: Commander, Naval Ship Systems Command (SHIPS 0361)

Subj: MACHLAB 5, Status report, Fiscal Year 1968, Deep ocean technology S4636/S4728, Submersible electric machinery and tandem propulsion tasks

Ref: (a) "Deep Ocean Technology Project," Technical Development Plan (DOT TDP) 46-36X, 20 March 1968
(b) "Deep Ocean Technology - Electric Drive System Program," MEL Status Rept 31/68, S4728 001 01, 16 Jan 1968
(c) "Tandem Propulsion System," Quarterly Progress Rept MEL 32/68, 13 Feb 1968

Encl: (1) Summary of Objectives, Funding, and Expenditures, DOT S4636, Fiscal Year 1968, Submersible Electric Machinery and Tandem Propulsion System Tasks (6 pages) (Restricted Distribution)
(2) Organization of DOT S4636, Submersible Electric Machinery and Tandem Propulsion System Tasks (2 pages)
(3) May 1968 Status Report, Submersible Electric Drive Systems Evaluation, Task Area S4728, Task 12313 (53 pages)
(4) May 1968 Status Report, DOT Fluids and Lubricants for Power Transmission and Pressure Compensation Systems on DSV, Task Area S4728, Task 12315 (11 pages)
(5) May 1968 Status Report, DOT DSV Electrical Protective and Switching Devices in Fluid Pressure Ambient, Task Area S4728, Task 12319, and DOT DSV Electrical Components and Materials in Fluid Pressure Ambient, Task Area S4728, Task 12317 (36 pages)
(6) May 1968 Status Report, DOT Electrical Penetrators and Cabling Systems for Deep Submergence Applications, Task Area S4728, Task 12321 (5 pages)

Encl: (7) May 1968 Status Report, DOT Electric Cables for Deep Submergence Vehicle Applications, Task Area S4728, Task 12314 (21 pages)
(8) May 1968 Status Report, DOT Tandem Propulsion System, Task Area S4728, Task 12320 (8 pages)

1. The subject tasks were initiated in Fiscal Year 1967 with exploratory development of machinery systems for advanced deep diving submarines. These tasks are part of reference (a) as approved by the Naval Material Command.

2. The objective of the submersible electric machinery tasks is to develop electric drive systems and control devices for use in propulsion and auxiliary systems for deep submergence vehicles. The background, authorization, and status of the tasks were initially reported in reference (b).

3. The objective of the tandem propulsion system task is to develop and evaluate a tandem propulsion system as a basis for determining its feasibility and effectiveness as a thrust device for advanced submersible vehicles. Currently there are four subtasks which were initially reported in reference (c).

4. These ongoing tasks involve the evaluation and definition of technology gaps and deficiencies and the development of improved materials, components, and vehicle subsystems applicable to the range of projected research and military vehicles. The objectives and approaches have been planned to provide interim solutions, design data, and long range improvements in a number of technical areas. The significant amount of available data and experience within and outside the Navy is continually being reviewed and analyzed to reduce redundant effort and to compare with analagous data. An integrated program and vehicle system approach considering subsystem functional relationships, commonality, safety, and logistics is fulfilled by intratask coordination and formal and informal reviews with the deep ocean technology (DOT) vehicle program management (NAVSHIPS) and the technical codes (NAVSEC).

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5. A summary of objectives, funding, and expenditures of each task is the subject of enclosure (1). The organization is presented in enclosure (2). Detail information on the status and results is contained in enclosures (3) thru (8).

H. C. Dalrymple

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By direction

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Enclosure (2)

ORGANIZATION OF DOT S4636
SUBMERSIBLE ELECTRIC MACHINERY AND
TANDEM PROPULSION SYSTEM TASKS

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Submersible Electric Machinery

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Electrical Protection and Switching, Task 12319

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Electrical Cables, Task 12314

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Electrical Connectors and Penetrators, Task 12318

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Enclosure (3)

MAY 1968 STATUS REPORT
DOT SUBMERSIBLE ELECTRIC DRIVE SYSTEMS EVALUATION
TASK AREA S4728, TASK 12313
WITH ANNEX I-3

Introduction. In deep submergence vehicles such as TRIESTE, ALVIN, and DEEPSTAR, the electric drives used for propulsion and auxiliary systems are located outside the manner pressure hull. Components such as motors, controllers, gear boxes, and protective devices are placed in hard shells or are flooded with oil or sea-water to allow operation in the high pressure environment. In the flooded components, high pressure rotating shaft penetrations and the associated high pressure seals and thrust bearings are eliminated. External components also provide some self-buoyancy, are better cooled by the seawater, are easier to connect to an external battery or other power source, and are removable without compromise of the pressure hull integrity. However, most existing equipment of this type has not provided the high reliability, low noise, light weight, and long life needed in Navy applications. For this reason, new, more promising equipment and systems now being proposed warrant Navy development and evaluation.

NAVSHIPS has established an "Electric Drive Systems" program with the objective of developing systems adequate for the Navy vehicles of the future. The program is divided into three phases: I-Drive system study, II-Evaluation of the state of the art of such systems, and III-System improvement. This report gives the status of Phase II, the evaluation of the state of the art of drive systems.

Objectives. The objectives of Phase II (Task 12313) are:

- To determine the availability of best "state-of-the-art" equipment by purchasing new components and evaluating them in system configurations.
- To evaluate various approaches to system design such as the use of a-c vs d-c motors, direct drive motors vs geared or traction-type speed reduction devices, oil compensated vs sea-water flooded vs hard shell components, etc.
- To provide guidance to Phase III, the systems improvement tasks, of this program so that fluids, bearings, insulation systems, connectors, switching devices, and other such elements will be improved as needed.
- To develop specifications for drive systems.
- To encourage manufacturers and other activities to develop improved components and system.
- To provide "spin off" systems or components, as available, for Navy use.

The accomplishment of these objectives is of course limited by the availability of funds and manpower and also by the state of the art itself.

Scope. The Program Summary of 10 July 1967, for this task, called for the purchase and evaluation of two each of four drive systems described in Table 1 (Systems 3, 4, 5b, and 6), in Fiscal Years 1968 and 1969. Since then, the scope of the task has been changed as follows:

- Evaluation of Systems 1, 2, 5a, 5c, and 7, with some of the hardware furnished from other programs, has been added.

- Purchase of the breadboard d-c controller for System 1 and the sea-water flooded motor for System 5a was added to complete these systems.

- Purchase of System 4 has been postponed until Fiscal Year 1969 because costs of the motor, speed reducer, and inverter controller were much higher than anticipated. In addition, the bids for the inverter-controller indicated that it is beyond the present state of the art.

- A contract has been negotiated and awarded to Stockpole Carbon Company under which they will investigate the operation of brushes as a function of commutation potential, brush material, brush pressure and fluid.

- Only one each of the components for these systems has been obtained due to lack of funds and the newly restricted purchasing limitations.

- Contracts for the failure mode and design analysis of the components in Systems 2, 3, 5a, 5b, and 6 have been postponed until Fiscal Year 1969 due to lack of funds.

Drive System Characteristics. Diagrams and basic characteristics of the drive systems in this program are presented in Annex I-3. The ground rules followed in the purchase of components were established as a result of the preliminary study (Phase I). These include the following:

- Only "external to the hull" components will be evaluated.

- An operational depth of 8000 feet is required; 20,000 feet desired.

- One thousand dives from surface to operational depth are required; 2000 dives desired.

- Immersion in seawater for 1000 hours is required; 2 years desired.

Table 1
Drive Systems to be Evaluated
DOT Submersible Electric Drive Systems Project
Revision May 1968

No.	Input	HP	RPM	Motor	Speed Reduction	Controller	Goal
1	115 vdc	17	600	d-c shunt	single planetary gear	breadboard d-c chopper	low weight
2	variable frequency 220v 400Hz	12	140	a-c induction	harmonic drive	None	low weight
3	100 to 140 vdc	7.5	600	d-c series	single reduction gear	chopper, oil compensated	low weight
4	100 to 140 vdc	15	90	a-c induction	double reduction gear	inverter in pressure case	long life
5a	100 to 140 vdc	7.5	600	a-c induction seawater flooded	none	inverter oil compensated	long life low noise
5b	100 to 140 vdc	7.5	600	a-c induction oil flooded	none	inverter oil compensated	long life low noise
5c	100 to 140 vdc	7.5	600	a-c induction MEL design	none	inverter oil compensated	long life low noise
6	100 to 140 vdc	15	90	d-c shunt	traction drive double reduction	chopper in pressure case	low weight low noise
7	100 to 140 vdc	18	90	brushless	comp planetary gear	attached oil compensated	high efficiency low weight

- An operational life of 1000 hours without maintenance is required, 2000 hours desired, except that in d-c motors, brushes may be replaced every 400 hours and fluid every 100 hours.

- Propeller reversal is required with up to half the system life in the backing direction.

- Sixty full speed reversals in 30 minutes are required with time for cool off and ten such tests performed.

- Transient loads of up to twice rated torque must be accommodated for 3 minutes out of every 10 minutes of operation.

- Overload and short circuit protection of the controller and motor is required with remote or automatic resetting capability. Current limiting to 200% of rated input is preferred over "crowbar" or other such shut-off-type systems.

- A motor speed indicator is required.

- Propeller speed control from rated speed to within a dead band of 0 ±10% of rated speed is required, 0 ±4% desired, in response to a +10 to -10 vdc signal, with 4% linearily required.

- Oil filled components with rotating shaft seals should contain double seals with separate cascading pressure compensation.

- Where a motor and speed reducer are joined, a common fluid must be employed but each must contain its own bearings.

- Oil filled components must contain a sea-water leakage detector.

- A-C motors must withstand sea-water leakage - 4 hours minimum, 100 hours desired; operation at rated load and seawater flooded.

- Sliding vs rolling contact bearings are desired.

- Systems must operate on 120 ±20 vdc battery power, with transients to 165 vdc.

- Power may not be fed back into the battery to provide braking, etc.

- Connectors must be per Military Specification MIL-C-24217.

Procurement Status. The status of the procurement of components for all systems is given in Table 2. As indicated, contracts have been placed for all components except the following:

Table 2
Procurement Status
DOT Submersible Electric Drives Systems Project
Revision May 1968

System	Component Parts of System	Present Status: RFQ Sent	Present Status: Bids Submitted	Approx Date: Contract Let	Approx Date: Hardware Delivered	Probable Supplier
17-hp d-c traction drive system (No. 1)	17-hp, 115-v submersible d-c motor	purchased under Sub-project S-F013 01 14, Task 11378, Contract N00161-67-R-0146			presently on board	Lear Siegler, Inc. Cleveland, Ohio (sole source)
	17-hp submersible single stage planetary reduction (5.14-1) 600 rpm output					
	"breadboard" solid state 17-hp d-c motor controller	11/20/67 N00161-68-R-0151	12/15/67	12/18/67 N00161-68-C-0151	6/30/68	Lear Siegler, Inc., Cleveland, Ohio (sole source)
12-hp, 400-Hz a-c harmonic drive (motor & drive assembled are one complete sealed unit (No. 2)	12-hp, 400-Hz a-c submersible motor and harmonic drive	purchased by NAVSHIPS under Sub-project S-F013-07-02, Task 1846		12/31/64 N00592165	7/30/68	United Shoe: motor produced by General Electric for United Shoe
	cables					
	connectors				5/1/68	D. G. O'Brien
7.5-hp geared d-c drive system (No. 3)	7.5-hp series wound submersible d-c motor	10/16/67 N00161-68-Q-136	12/22/67	2/12/68	8/12/68	Hoover Electric, Los Angeles, Calif. (sole source)
	7.5-hp, 600 rpm output reduction gear, submersible	10/16/67 N00161-68-Q-136	12/22/67	2/12/68	8/12/68	Hoover Electric, Los Angeles, Calif. (sole source)
	7.5-hp, 100 vdc fluid compensated, solid state, submersible motor controller	11/6/67 N00161-68-Q-0143	12/20/67	3/4/68	9/4/68	J.C. Carter Co., Costa Mesa, Calif. (sole source)
	d-c distribution assembly, submersible	distribution box Systems 3 and 5				Hartman ?
		interconnecting cables				Portsmouth Naval Shipyard
		connectors (Systems 3&5)		4/15/68	6/15/68	Cannon Electric
15-hp a-c double reduction drive system, submersible (No. 4)	15-hp a-c induction motor, submersible	12/8/67 N00161-68-Q-0139	1/7/68	Deferred Until Next Fiscal Year Because of Cost		open bid
	15-hp, 90 rpm output reduction gear, submersible	12/15/67 N00161-68-Q-0152	1/14/68			open bid
	15-hp solid state, hard shell, submersible, inverter controller	12/15/67 N-00161-68-Q-0159	1/14/68			open bid
	distribution assembly, submersible					

System	Component Parts of System	Present Status: RFQ Sent	Present Status: Bids Submitted	Approx Date: Contract Let	Approx Date: Hardware Delivered	Probable Supplier
7.5-hp a-c direct drive system (No. 5a)	7.5-hp a-c induction motor, submersible	11/20/67 N00161-68-Q-0153	1/2/68	3/21/68	9/21/68	J.C. Carter Co. Costa Mesa, Calif.
7.5-hp a-c direct drive system (No. 5b)	7.5-hp a-c induction motor, submersible	11/20/67 N6 1533-7346-1676 Contract through NPO	5/21/68	6/30/68 ?	1/1/69	Franklin Electric
	7.5-hp fluid compensated, solid submersible, inverter controller	11/7/67 N00161-68-Q-0141	12/20/67	3/8/68	9/8/68	J. C. Carter Co. Costa Mesa, Calif. (sole source)
	distribution system (see System 3)					
17-hp d-c drive system (No. 6) (completed design started as System 1)	17-hp submersible d-c motor	unsolicited proposal	3/22/68	6/30/68 est.	2/1/69 est.	Lear Siegler, Inc. Cleveland, Ohio (sole source)
	17-hp solid state motor speed controller	contracting handled by NPO N61533-7346-1115 in negotiating stage		6/30/68 est.	12/30/68 est.	open bid
	distribution system	specifications being written		6/30/68	11/15/68	
	15-hp traction drive speed reducer, submersible	11/22/67 N00161-68Q-0152	12/21/67	6/30/68 delayed NPO	12/30/68	New Departure Hyatt Bearings Division of General Motors
18-hp brushless d-c motor submersible (Nadyne) drive system (No. 7) (motor & converter speed controller form one unit)	Nadyne 18-hp brushless motor	design and specification under S-F013-07-02, Task 4396, N00024-67C-5427		Phase II hardware 2/15/68	11/30/68	North American Rockwell
	18-hp converter-speed controller					
	18-hp planetary gear speed reducer	NAVSEC placing R&D contract		6/30/68 est.	12/30/68 est.	North American Autonetics
	distribution system					

a. The 7 1/2-hp a-c motor from Franklin Electric for use in System 5b.

b. The 17-hp d-c motor from Lear Siegler, Incorporated, for use in System 6.

c. The 15-hp traction drive from New Departure Hyatt Bearings of General Motors for use in System 6.

d. The 17-hp d-c controller for System 6.

e. The 18-hp geared speed reducer from North American for System 7, being purchased by NAVSEC.

f. Portions of the 7 1/2- and 17-hp distribution assemblies for Systems 2, 3, 5, 6, and 7. Connectors have been purchased.

Of these items, the only contracts which may not be let by 30 June 1968 are Items a and f. Item a, being purchased by NPO, required a resubmittal of a proposal by Franklin by 27 May 1968 on a sole source basis. It is planned to award the contract by 30 June or shortly thereafter. The specifications for the cables and the distribution box assemblies are being prepared for contract and should be processed near the end of June.

System Tests. The test program status and schedule are outlined in Table 3. The general test criteria for bench, pressure, and shallow water in situ testing is presented in Annex I-3 to this status report. Deviations do exist because of system or component differences. For example, System 1 contains a breadboard controller, a motor with stuffing glands instead of connectors, and a speed reducer without thrust bearings and with a female spline. Therefore, special pressure tests will be made in an oil filled container, and no shallow water tests will be made.

Preliminary test and evaluation has been made on the 17-hp, 115 vdc motor for System 1. This work was conducted under Sub-project S-F013 01 14, Task 11378, and is reported in MEL Report 150/68.

The status and cost of test facilities are given in Table 4. A detailed description of the facilities and general arrangement appears in Annex I-3.

Problem Areas. The following problems have been encountered or are anticipated in the development of adequate submersible electric drive systems for Navy vehicles:

The limited immediate market potential for deep submergence drives makes it difficult to obtain equipment at reasonable cost or to interest manufacturers in the development of new equipment. It would be advantageous to tie in the development of these components with programs requiring higher production quantities. Oil drilling equipment, deep running torpedoes, and swimmer delivery vehicles are examples of such programs.

Table 3
Detail Test Schedule
DOT Submersible Electric Drive Systems Project
Revision May 1968

System	Component or System Test	Test Status	Start Testing	End Testing
17-hp d-c drive system (No. 1)	17-hp, 115 vdc submersible d-c motor bench test	preliminary detailed procedure written	pre-evaluation test*	
			7/21/68	8/1/68
	single stage planetary	preliminary detailed procedure written	7/21/68	7/30/68
	"breadboard" controller solid state 17-hp bench test	preliminary detailed procedure written 12/1/67	7/21/68	8/1/68
	system bench test		8/5/68	9/13/68
	system pressure test		9/13/68	10/13/68
	system shallow submergence test		NA	
12-hp, 40-hz a-c harmonic drive (motor and drive are one sealed unit) (No. 2)	12-hp, 400 hz a-c submersible motor and harmonic drive unit bench test	preliminary detailed procedure written	8/4/68	8/14/68
	system pressure test	preliminary system detailed test procedure written	9/30/68	10/30/68
	system shallow submergence test	preliminary system detailed test procedure written	8/19/68	9/19/68
7 1/2-hp geared d-c drive system (No. 3)	7 1/2-hp series wound submersible d-c motor bench test	preliminary detailed procedure written 12/1/67	8/15/68	8/25/68
	7 1/2-hp, 600 rpm output reduction gear submersible bench test	preliminary detailed procedure written 12/1/67	8/15/68	8/25/68
	7 1/2-hp, 100 vdc fluid compensated solid state motor controller bench test	preliminary detailed procedure written 12/1/67	9/7/68	9/17/68
	d-c distribution assembly submersible bench test	preliminary detailed procedure written 1/31/68	11/16/68	11/26/68
	system bench test (without distribution assembly in system)	preliminary system detailed test procedure written	9/24/68	10/4/68
	system pressure test	preliminary system detailed test procedure written	10/5/68	11/5/68
	system shallow submergence test	preliminary system detailed test procedure written	11/6/68	12/6/68
15-hp a-c double reduction drive system submersible (No. 4)	15-hp a-c induction motor submersible bench test	deferred until Fiscal Year 1969 because of cost		
	15-hp, 90 rpm output reduction gear, submersible bench test			
	15-hp solid state hard shell submersible inverter-controller bench test			
	distribution system submersible bench test			

*Pre-evaluation test conducted under Sub-project S-F013 01 14, Task 11378, Contract N00161-67-R-0146 (see MEL Report 150/68)

Table 3 (Cont)

System	Component or System Test	Test Status	Start Testing	End Testing
15-hp a-c double reduction drive system submersible (No. 4) (Continued)	system bench test	deferred until Fiscal Year 1969 because of cost (Continued)		
	system pressure test			
	system shallow submergence test			
7 1/2-hp a-c induction motor submersible bench test (No. 5)	7 1/2-hp a-c induction motor submersible bench test	preliminary detailed procedure written	(a)9/22/68 (b)1/1/69 (c)	(a)10/2/68 (b)1/12/69 (c)
	7 1/2-hp fluid compensated, solid state, submersible inverter controller	preliminary detailed procedure written	(a)9/10/68	(a)9/20/68
	distribution system 3 bench test			
	system bench test	general test procedure available	(a)10/4/68 (b)1/15/69	(a)10/14/68 (b)1/25/69
	system pressure test	general test procedure available	(a)10/16/68 (b)2/1/69	(a)11/16/68 (b)3/4/69
	system shallow submergence test	general test procedure available	(a)11/19/68 (b)3/4/69	(a)12/19/68 (b)4/4/69
17-hp d-c drive system completed design (started as system 1)	17-hp submersible d-c motor bench test	possible let 6/30/68	2/1/69	2/11/69
	17-hp solid state hard shell motor speed controller bench test	contracting handled through *NPO; award 6/30/68*	1/3/69	1/13/69
	distribution system		11/21/68	12/1/68
	15-hp traction drive submersible bench test		1/1/69	1/11/69
	system bench test	general test procedure available	2/18/69	2/28/69
	system pressure test	detailed test request will be prepared 7/29/68	3/1/69	4/1/69
	system shallow submergence test	detailed test request will be prepared 9/3/68	4/4/69	5/4/69
18-hp brushless d-c motor submersible (Nadyne) drive system (unit system)	Nadyne 18-hp brushless motor		12/1/68	12/11/68
	18-hp converter speed controller		12/1/68	12/11/68
	distribution system (see system 6)	in process of defining system; therefore, cannot plan test in detail		
	speed reducer		1/1/69	1/11/69
	system bench test		1/12/69	1/22/69
	system pressure test		1/23/69	2/23/69
	system shallow submergence test		2/24/69	3/24/69

Table 4
Test Facilities Status
DOT Submersible Electric Drive Systems Project
Revision May 1968

Type Test	Description	Status	Operational Date
component bench testing	general laboratory testing & staging areas	available laboratory areas are presently being modified to facilitate initial phases of investigation, to include inspection, both mechanical and electrical, as well as testing to determine the dynamic characteristics of all components	6/68
	labor for fabrication of test stands; jigs and fixtures required for initial phase of instrumentation		N/A
pressure testing	(1) Vessel 4000 psi hydrostatic 24" I. D. 22 ft. long 16" access.	presently available and operational	12/8/67
	Supporting Hydraulic Equipment (1) Worthington Triplex pump (1) Sprague pump (backup)		
	(1) Tank G - Vessel 5000 psi hydrostatic pressure 20" I. D. 8-1/2 ft. long 20" access supporting hyd.	design completed, cylinder presently available, materials on hand	June 1968
	Supporting Hydraulic Equipment (1) Sprague pump (1) SC Hyd. pump	available	
	Supplementary Equipment* 10,000 psi seawater heat exchanger	specification out for quotes	July 1968
	10,000 psi seawater circulating pump	specification out	July 1968
	Glycol-seawater chiller * Common useage for tank G and H	specification out for quotes	July 1968
	(1) Vessel 12,000 psi hydrostatic pressure 0-4000 psi cycling capability 4 ft. I. D. 8 ft. long 4 ft. access (ANNADIV NSRDC deep submergence complex Tank B)	being fabricated Sun Ship, Chester, Pa. funded under another NAVSHIPS program.	Late 1968
	(1) Vessel 12,000 psi hydrostatic pressure 0-4000 psi cycling capability 10 ft. I. D. 25 ft. long 10 ft. access (ANNADIV NSRDC deep submergence test complex Tank A)	being fabricated Sun Ship, Chester, Pa. funded under another NAVSHIPS program.	Late 1968
	(1) Tank H - Vessel 7000 psi hydrostatic pressure 30" I. D. 7 ft. long 30" access support hydraulic and 2 Ton cooling equipment	* see note for "G" Tank contract award 2/68	Aug 1968
	labor for fabrication of pressure vessel stands, machining end plug and associated piping and cooling system required		N/A

Table 4 (Cont)

Type Test	Description	Status	Operational Date
shallow submergence propeller testing	(1) cantilevered rail extending beyond the sea wall, will be used for the lowering and raising of a five foot long platform in approximately twenty feet of water. Instrumentation and control center design added to site	modification required to adapt system mountings funded on in-house funds.	July 1968
	(2) twenty foot long platform capable of being lowered and raised to a depth of twenty feet with a catwalk built on piles surrounding the perimeter of the platform for operator access	presently available	Dec 1968
	(3) site preparation and input power cabling for equipment and instrumentation	design complete, fabrication started	July 1968
	labor for site preparation and fabrication of test stands and fixtures required for initial stage of testing		N/A

- Systems capable of precise and efficient speed control over a very wide range of speeds are complex, expensive, and may be unstable, especially in the very low speed region. As experience with DSRV becomes available, it may be found that such close and varied control is not required. If so, simpler approaches to the design of motor controllers, motors, and speed reducers should be pursued. For example, closed loop speed control can be avoided and design of both water lubricated bearings in a-c machines and commutation in d-c machines can be optimized.

- Good hard shell housings for power controllers require careful design because one material cannot simultaneously meet requirements for low corrosion and fouling, high thermal conductivity, high strength, and low weight. Aluminum alloy presently being used offer good strength-to-weight ratios, and good thermal conductivities; but because they are corrosive in seawater, they require extensive protection and frequent inspection and maintenance. The copper alloys can provide corrosion and fouling protection and good thermal conductivity but suffer in strength-to-weight ratio. Steels and titanium offer good corrosion resistance, but their thermal conductivity is low. Manufacturers have found hard shell housings to be a major problem in the development of controllers. For this reason, if the oil compensated electronic controllers in this program prove reliable, they may represent the best approach for future power electronic development.

- There has been insufficient competition with J. C. Carter Company for controllers in this program. This is because J. C. Carter has developed high frequency high power choppers which can be used in both a-c and d-c applications and oil-compensated power electronic techniques which can be used instead of hard shell encapsulated designs. To provide some competition in both the d-c and a-c motor controller areas, it is recommended that:

    - Work on Lear Siegler breadboard d-c controller in System 1 be extended in three phases:

      Phase I—Complete the logic circuitry to provide dynamic breaking and closed loop speed control and add emergency bypass capability.

      Phase II—Develop a hard shell package for the electronics and an oil filled package for the associated chokes and contactors.

      Phase III—Produce a complete controller for system evaluation.

    - An advanced a-c controller be developed after careful review of the Westinghouse DSRV development program and the Lockheed deep quest development program. This review can be completed by 1 January 1969.

Present funding for Fiscal Year 1969 does not provide for these recommendations.

Annex I-3
May 1968 Status Report
DOT Electric Drive Systems
Evaluation Project

Part A—Drive System Description

Part B—General Test Description

PART A

DRIVE SYSTEM DESCRIPTION

SYSTEM 1 - 17-HP, D-C, 600 RPM (Table I3-1)

17-HP D-C Motor and Speed Reducer Gear Assembly (Figure I3-1)

This 17-hp drive contains an oil filled, reversible 120 vdc motor and a single stage planetary gear speed reducer.

The motor is a 4-pole, separately excited, shunt-wound machine with interpoles and compensating windings. It operates at 120 volts, 150 amperes, with a 3000 rpm, 17-hp output. Reversing of the motor is accomplished by reversing the polarity of the shunt field, and motor speed is controlled by adjusting the armature voltage or current. Speed readout is given by the output signal of a magnetic pickup, adjusted near a 60-tooth actuator which also contains a centrifugal filter so located as to remove large brush and commutator wear products. Cables enter at the rear of the motor through nylon stuffing tubes.

The motor, together with the planetary gear, forms a compact drive unit weighing 128 pounds (filled with oil). The unit is filled and compensated with MIL-L-6081C (Grade 1010) fluid which is free to circulate between the motor and speed reducer. The unit is sealed by two shaft seals at the output of the speed reducer.

The speed reducer, which gives a 5 to 1 reduction, consists of three planet gears mounted on needle bearings with a removable pinion and internal ring. Circumferential slots are cut in the planet gears in an effort to decrease rotational pumping losses.

Breadboard D-C Motor Controller

Description

Speed control for this drive system is achieved by varying the armature current to the motor. The controller is made up of six discrete power modules connected in parallel, with each module using a 300-volt, 60-ampere transistor to switch power. The modules are operated at 110 vdc and up to 50-ampere output level. Armature current control is achieved by static pulse-width modulation derived from armature current level sensing and a d-c reference signal. By varing the reference signal, output current is made to change; therefore, motor output torque is made variable. Figure I3-2 is a schematic diagram of the controller and motor.

Six modules of the above description are connected in parallel, giving a 300 ampere maximum output. Each module uses a separate current ripple-reducing

reactor and "free-wheeling" diode. Also each transistor "chopper" is fused. The circuit logic is arranged in such a manner that loss of individual transistor module clears the fuse and disconnects itself from active operation. The loss of a module introduces gradual reduction of output current capability in steps of 50 amperes.

Since the remaining modules could be required to carry full maximum load, and thereby damage the remaining branches, additional protection against loss of all modules is included. The armature current level is sensed in each module independently so that any one of the modules can have full control of the operation. Thus, inoperative modules and their current-level sensing circuits are automatically excluded from complete performance of this armature current controller. As a result, the remainder of the control remains operative.

A 300-volt peak rating of the chopper provides a voltage safety level of twice the operating level.

The d-c current sensing is accomplished by a Mistor magnetic resistor placed in each module. Varying flux density in a small C core provides the necessary flux density level and therefore variation in Mistor resistance. This variation of resistance is detected by an analog comparator and converted to digital logic cable of controlling the power transistor chopper (motor driver).

By changing the command signal of -10 to +10 vdc, various current levels are achieved. An ON-OFF power switch is common to the field reversing device and activates a contactor rated at 300-volt, 300-ampere operating level.

The electronics are mounted on circuit boards and installed in a standard rack mount cabinet. This controller does not have emergency bypass features or a pressure housing.

SYSTEM 2 - 12-HP HARMONIC DRIVE (Table I3-2, Figure I3-3)

Description

The harmonic drive system consists of a 400-cycle motor which drives a propeller shaft by means of a harmonic drive speed reducer.

The motor drives a pair of eccentric rollers which radially deflect a thin circular ring having spline teeth formed on its outer periphery. This flexible circular ring is distorted into an elliptical shape and meshes at diametrically opposite points with a rigid ring, which has internal spline teeth. As the motor turns the eccentric rollers, the spline teeth on the flexible ring and rigid ring engage and disengage; the difference in the number of teeth determines the speed reduction ratio. The motor and eccentric roller mechanism are hermetically sealed. The propeller shaft is bolted to the rigid ring, and water-lubricated radial and thrust bearings are provided to support the ring and propeller-shaft assembly.

The principal advantages of the harmonic drive are:

- It permits positive drive through a hermetically sealed barrier thereby eliminating the necessity for mechanical shaft seals and the possibility of seawater intrusion into the motor and high speed portion of the drive mechanism.

- The meshing spline teeth are subjected to relatively low mechanical wear as the tooth motion is essentially radial engagement and disengagement rather than sliding contact.

The motor is designed for 400-cycle, 3-phase, 200-volt power and operates at 7600 rpm. Speed change is accomplished by varying the input frequency.

The propeller rotates at 140 rpm full speed through the harmonic drive reduction ratio of 55:1. Both motor and the high speed portion of the harmonic drive operate in JP-5 fuel oil. Pressure compensation is provided for operation at pressures up to 9000 psi.

SYSTEM 3 - 7 1/2-HP DC (Table I3-3)

Distribution Assembly

The distribution box for the 7 1/2-hp d-c system will be fluid-filled, pressure compensated, made of 316 stainless steel, and will contain protective devices for the system. The protective devices are remote operating contactors in both input power lines that make and break under maximum current (200% rated system current), and a remote resetting, fast acting circuit breaker that isolates the system from the power source in the event of a short circuit or sustained overload in excess of 225 amperes (300% rated system current). The normal mode of energizing the drive system is to set the control signal to the motor controller to zero, thereby reducing line current to less than 5% rated system current. The contactors are then closed under essentially no-load conditions and the control signal to the motor controller set at the desired system operating point. Remote operation for the contactors and circuit breakers is controlled by a d-c power supply with a voltage range from 21 to 29 vdc. A current sensing shunt is also located in the distribution box to sense total line current. In the event of circuit breaker malfunction, the visual readout of the signal from the current sensor will allow the operator to manually shut down the system.

D-C Motor Controller (Figure I3-4)

The controller to be used in the 7 1/2-hp d-c drive system is a solid state, high frequency, pulse-width modulated, fluid compensated, chopper regulator motor controller. The controller housing is filled with dielectric oil which is pressure compensated to approximately 2 psi above ambient pressure. The total system is designed to be submerged in seawater at pressures up to 13,500 psi.

The chopper regulator is a high frequency chopper using silicon transistors in order to achieve maximum efficiency. Each pulse from the chopper is monitored to provide current limiting. If any pulse current becomes higher than a safe level, that pulse is immediately terminated and another pulse is initiated after a short interval. As long as a reasonable amount of inductance is always provided in series with a regulator, it is possible for the chopper to run into this current limiting condition indefinitely. Because this is to be operated with a series motor, the inductance would always be adequate and this could occur. An example of this would be both contactors closed at the same time by some malfunction in the wiring, causing the armature to be shorted out.

In normal operation of the motor control, the reversing contactors will never be actuated until the voltage from the chopper regulator has been reduced to zero. Thus, the contacts will never be subjected to switching currents either turning on or off. Electronic interlock circuits make it impossible to close both contactors at the same time.

The switching mode regulator utilizes 12 silicone transistors, in parallel, with each one fused in the base and emitter circuit. It is thus possible for one or two transistors to short out without interfering with the regulator operation. If an excessive number of fuses blow, causing the regulator to be inoperative, a large SCR in parallel with the chopper regulator will be turned on. The electronic interlock which prevents operation of the contactors with any voltage across the contact will make it impossible for either contactor to be closed by means of the normal control. The operator can then remove the mechanical guard from the emergency operating switch allowing either the forward or the reverse contactor to be closed.

The controller operates from a command signal of ± 10 vdc corresponding to full speed ahead and full speed reverse. The impedance to the control signal is in excess of 10,000 ohms.

The regulator, the reversing contactors, and all electronics will be enclosed in a housing as shown in Figure I3-4. The housing will be constructed of Inconel 625.

7 1/2-HP D-C Motor (Figure I3-5)

The 7 1/2-hp motor is a 100 vdc, oil-filled, 4-pole, series wound machine. At rated load it draws 75 amperes at 3500 rpm. Motor speed control is accomplished by adjusting the input voltage, and the motor is reversed by switching the polarity of the series field. Speed readout is given by the output of a magnetic pulse generator. Three radially mounted MIL-C-24217 connectors are provided; two for power, and one for speed and leakage-sensing.

The motor is designed for normal operation, filled with Hoover Fluid 2, and contains a volume-compensating and pressure equalizing chamber.

Speed Reducer Assembly (Figure I3-5)

The speed reducer is a dual-path single-stage, internal-gear reduction unit. The motor pinion engages and directly drives the two idler gears (dual path) which engage a single reduction internal gear, and, through a spline, drives the output propeller mounting shaft. An input of 3500 rpm through the 5.87:1 reduction produces a 600 rpm output. The speed reducer will operate in the same fluid in which the motor operates. This fluid is a proprietary hydrocarbon fluid, designated Hoover Fluid 2. The sea-water-exposed housing of the speed reducer and the output shaft are fabricated from 316L stainless steel. Redundant carbon face seals (2) serve as dynamic seals on the output shaft of the speed reducer. A fitting between the two carbon face seals is provided for the attachment of an external pressure compensator.

SYSTEM 5 - 7 1/2-HP A-C DIRECT DRIVE (Table I3-5)

Distribution Assembly

The distribution assembly for the 7 1/2-hp a-c system will be oil filled, pressure compensated, and made of stainless steel housing containing circuit breakers and contactors. The circuit breakers have a 225-ampere rating, capable of being remotely reset by a 21 to 28 vdc signal. The contactors rated at 150 amperes will also be capable of responding to a remote d-c signal of 21 to 28 volts under essentially no-load conditions. A current sensing shunt is placed in the line to measure any line current fluctuations and also provides a visual readout to personnel for checking operational status of breakers and contactors. A sea-water detector indicates any intrusion of seawater into the enclosure. Externally mounted Cannon MIL-C-24217 underwater connectors (3) provide for all inputs and outputs.

Inverter-Controller (Figure I3-6)

The inverter-controller unit is solid-state, variable-frequency, three-phase, oil-compensated and operates in a frequency range of 0 to 43 hertz. Output voltage wave forms is square, 97-volt average, 31-Hz, 3-phase. The unit incorporates dynamic braking and current limiting at approximately 200% of rated motor load. Under steady-state load conditions the inverter is capable of reversing and continuously varying the drive assembly speed in response to a d-c control signal of ±10 volts. Impedance of this control signal is in excess of 10,000 ohms.

The inverter-controller is energized by a d-c power source having a nominal voltage of 120 volts operating in range of 100 to 140 vdc. The maximum transient predicted will be 165 vdc.

A gear-tooth tachometer generator with a relatively high frequency output is used to achieve a constant slip frequency. The gear, with several hundred teeth, will actuate a magnetic pickup providing a digital readout of slip frequency. An advantage of this plan is that the need for a digital to analog converter is avoided.

The inverter is equipped with a pressure-compensating sump which will correct for changes in fluid volume due to changes in temperature and pressure. A sea-water seepage detector is placed at a low point in the package to indicate any intrusion of seawater into the housing. The inverter pressure-compensating system and all the electronics are enclosed in a housing constructed of Inconel 625. Cooling of the unit will be accomplished primarily by conduction of heat to the outer circular case. The housing is filled with silicon oil which conducts a small portion of heat to the outer case. Five MIL-C-24217 underwater connectors, lock-nut type, are mounted on the housing. The entire unit is designed to operate in seawater at operating pressures of 13,500 psi.

<u>7 1/2-HP J. C. Carter A-C Motor</u> (Figure I3-7)

A 6-pole a-c sea-water flooded, squirrel cage induction motor with a variable speed capability is directly connected to a propeller. The motor operates from a 97-volt average line to line square wave, 31-Hz input, and has an output of 7 1/2 hp at 600 rpm. The duty is continuous at all input voltages.

The stator is hermetically sealed and is enclosed in an Inconel 625 housing. The stator chamber is filled with dielectric oil and has a metal bellows to compensate for changes in fluid volume due to pressure or temperature changes.

The rotor is impregnated and canned in a corrosion resistant metal housing. The rotor chamber is flooded with filtered seawater upon submergence of the motor. A centrifugal pump provides pressure for bearing lubrication and coolant circulation.

The bearings are designed for operation in seawater for 150% of total load consisting of rotor weight, propeller weight, and magnetic side pull. The thrust bearings are capable of reverse and forward, operation in the sea-water medium.

Instrumentation includes probes located at each end of the stator chamber to detect small amounts of seawater that may enter the stator enclosure. In addition, a magnetic pickup for speed indication is contained in the hermetically sealed stator chamber and is protected from corrosive effects of the seawater.

<u>7 1/2-HP Franklin Electric A-C Motor</u> (Figure I3-8)

This motor is a 6-pole, a-c, oil filled, squirrel cage induction motor with a variable speed capability. It is directly connected to a propeller. The machine responds to an 87-volt rms, 31-Hz, 3-phase, a-c input, with a shaft output of 7 1/2 hp at 560 rpm. The duty is continuous at all input voltages.

The stator consists of a wound core embedded in an epoxy resin and assembled in an all-welded 17-4 Ph stainless steel enclosure, which will withstand pressure in excess of 6000 psi. An Inconel-X liner is utilized in the stator bore.

The rotor assembly consists of the copper bar rotor core assembled on a 17-4 Ph stainless steel shaft. Conductor bars and end rings are copper. A pump is built into the shaft to circulate the lubricant through the system.

Rolling element bearings are lubricated by MIL-H-5606 hydraulic fluid and are capable of operation in all positions horizontal to vertical. The thrust bearing will be capable of reverse as well as forward operation in MIL-H-5606 fluid lubrication condition but not in sea-water lubricated operation.

The primary pressure equalization chamber is mounted on the side of the motor and contains a spring loaded diaphragm. There is provision for connection to a secondary pressure equalization chamber and reservoir for continued operation in the event of a malfunction in the primary system. A double shaft seal is utilized with facilities provided for connection of the volume between the seals to the secondary pressure compensation system fluid.

Instrumentation includes a magnetic pickup to indicate rpm output, and a seawater indicator shows presence of seawater in the lubricating fluid. Separate connectors, in accordance with MIL-C-24217, are used to bring out the magnetic rpm pickup and salinity detector leads.

SYSTEM 6 - 17-HP D-C 90 RPM (Table I3-6)

Distribution Assembly

The power source will have an operating voltage range of 100 to 140 vdc with a nominal rating of 120 vdc. Maximum voltage transient will be 165 vdc. The battery pack shall be fused to protect against a short circuit condition.

The distribution assembly will consist of circuit breakers, electrical contactors, and current sensors, which measure line current. The breakers and contactors have remote setting capability and operate on a 21 to 29 vdc signal. The components are housed in a stainless steel cylinder, 15 inches in diameter and 15 inches in length. The container is oil compensated and contains a detector to indicate any intrusion of seawater. Circuit breakers have a rating of 450 amperes with contactors having a 300-ampere trip capability. MIL-C-24217 underwater connectors are mounted on the housing to accommodate input and output lines.

The interconnecting cabling assemblies consist of MIL-C-24217 underwater plugs molded to standard Navy underwater cable.

D-C Motor Controller

The motor controller is currently under contract negotiation.

17-HP D-C Motor (Figure I3-9)

This 17-hp motor is the follow-on of the prototype motor in System 1. It is a 100 vdc oil filled, 4-pole, shunt-wound machine with interpoles and compensating windings. At rated load it draws 165 amperes and turns at 3000 rpm (nominal). Motor speed control is accomplished by adjusting the armature voltage, and the motor is reversed by switching the polarity of the shunt field. Speed readout is given by the output signal of a magnetic pickup adjusted near a 60-tooth actuator. This actuator also contains a centrifugal filter to remove large particles of brush and commutator wear products. Three MIL-C-24217 connectors are mounted around the drive end adapter flange; one for power, one for speed and leakage sensing, and one for instrumentation test leads.

A sea-water detector is located in the cavity between the motor and speed reducer so that any sea-water leakage past the shaft seals in the speed reducer will be sensed before it enters the motor enclosure.

The motor is designed for normal operation filled with oil. A spring-loaded compensator which maintains the pressure of the combined motor and speed reducer at 3 psi above the pressure of an external fluid reservoir is included in the motor.

Traction Drive (Figure I3-10)

The roller traction-type speed reducer is a planetary drive mechanism which utilizes lubricated rolling contacts for power transmission. This drive transmits torque by means of the smooth and continuous action of the tractive forces within the rolling contact regions. The traction drive does not exhibit the periodic vibratory disturbances generated in gear drives, and therefore provides a transmission which has a low noise-generation characteristic.

The traction drive utilizes a two-stage planetary arrangement. The first-stage sun roller is driven by the attached motor through a ball spline-type flexible coupling. The first-stage planet carrier is attached to the second-stage sun roller. The propeller shaft is attached to the second-stage planet carrier. Provision is made to automatically adjust the roller preload in both stages to changes in the output torque demand. This is accomplished by a ball and wedge device attached to the sun rollers. Roller preload is reduced at partial output loads, thereby greatly increasing the fatigue life of the mechanism.

The performance of a traction drive is dependent upon the traction property of the lubricating fluid used. This traction property bears no direct relationship to viscosity and must be determined experimentally. If a different fluid is substituted in lieu of the one for which the drive has been designed the possibility exists that the fatigue life of the mechanism will be reduced. Fluid selection is therefore more critical than for gear transmission.

SYSTEM 7 - 18-HP BRUSHLESS MOTOR SYSTEM (Table I3-7)

Distribution Assembly

The distribution system will be the same as the one described in System 6.

18-HP Motor (Nadyne) (Figure I3-11)

The Nadyne motor is a 6-pole, 3-phase self-synchronous, brushless machine. It features a smooth solid rotor which employs alternate north and south salient poles separated by nonmagnetic material. These poles are established by means of a d-c excited field winding on the stator of the machine. A-C power is applied to a second set of windings on the stator. With an input of 52 volts rms, 180 Hz, 100 amperes rms, the motor delivers 18 hp at 3600 rpm. Field excitation requires a maximum voltage of 100 vdc and a maximum current of 4 amperes. The motor speed control is provided by varying the stator a-c voltage and field d-c current, and reversing is accomplished by reversing the field current.

The interior of the motor is filled with silicone oil (GE-SF 1143, ICS) and pressure compensated to slightly higher than sea-water ambient pressure.

The motor is designed for direct attachment to the converter with pressure compensation by means of the converter compensator. A diaphragm between the motor and converter allows compensation without interchange of fluid so that if seawater leaks into the motor, it will not ruin the converter.

Motor Controller (Figure I3-11)

The converter consists of an inverter, series voltage regulator, motor field power supply, frequency control, speed control, and associated auxiliaries (Figure I3-12). It is filled with silicone oil which is pressure compensated to ambient pressure.

The converter receives 120 vdc and supplies variable frequency and variable voltage to the motor a-c stator windings. The frequency is controlled by direct feedback from the rotor and varies from 0 to 200 Hz, according to motor speed.

The design of the converter is such that the failure of a single device in the power handling section results in a 25% drop in current available to the motor. Also a single device failure does not cause load redistributions or voltage transient conditions which could increase the failure probability of the remaining current-carrying devices.

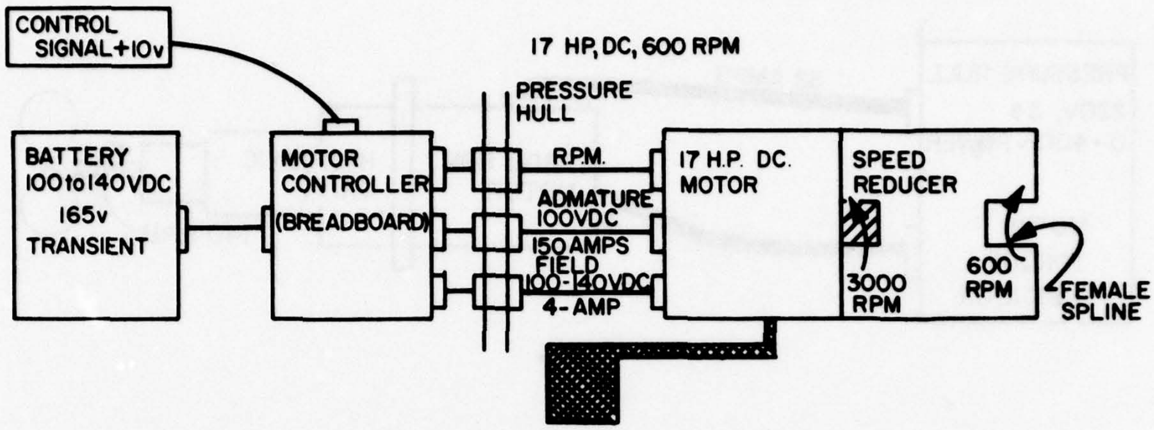
Speed Reducer Assembly (Figure I3-13)

The speed reducer is a two-stage planetary gear mechanism. Utilization of multiple-load-path planetary gearing permits moderate tooth loads without the necessity for large pitch diameters which would create high fluid friction losses.

The arrangement of the gearing consists of a fixed planet carrier in the first stage and a rotating planet carrier/fixed ring gear for the second stage. The motor drives the first-stage sun gear through a splined coupling. The propeller shaft is integral with the second-stage planet carrier. Roller bearings are used throughout to support rotating elements.

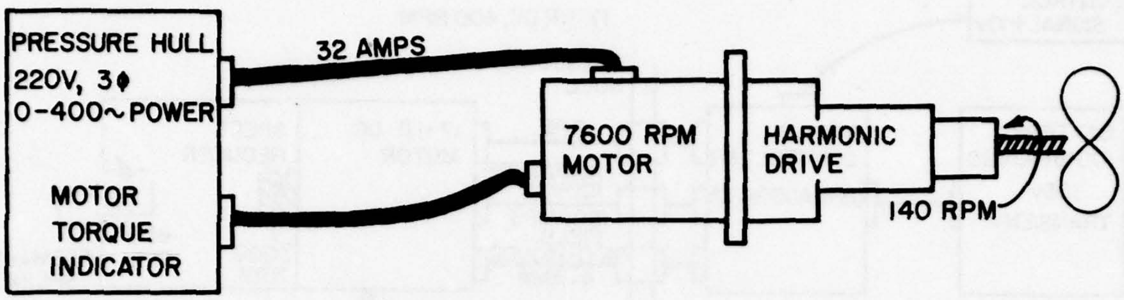
The speed reducer will be lubricated with the same fluid as the Nadyne motor (GE - SF 1143, ICS) silicone oil. Although this fluid is a radical departure from usual gear lubricants, preliminary analysis indicates that it will perform satisfactorily under relatively low gear tooth loadings.

Table I3-1
System 1 - 17 HP, DC, 600 RPM



Type	D-C Chopper	Neoprene Bladder	DC Shunt Wound	Single-Stage Planetary
Manufacturer	Lear Siegler		Lear Siegler	Lear Siegler
Weight in Air (Filled), lb.	—		100	28
Housing Length, in.	—		19	8-1/2
Body Diameter, in.	—		6.0	4-1/4
Case Material	—		303 Stainless-Steel	6061 Aluminum
Fluid and Viscosity at 100° F	—		MIL-L-6081C 10 cs	MIL-L-6081C 10 cs
Special Features	Breadboard Model		Proprietary Brush Compensation Centrifugal Filter 3.5 L/D Ratio Stuffing Tubes on Cables	Circumferential Slots in Planet Gears

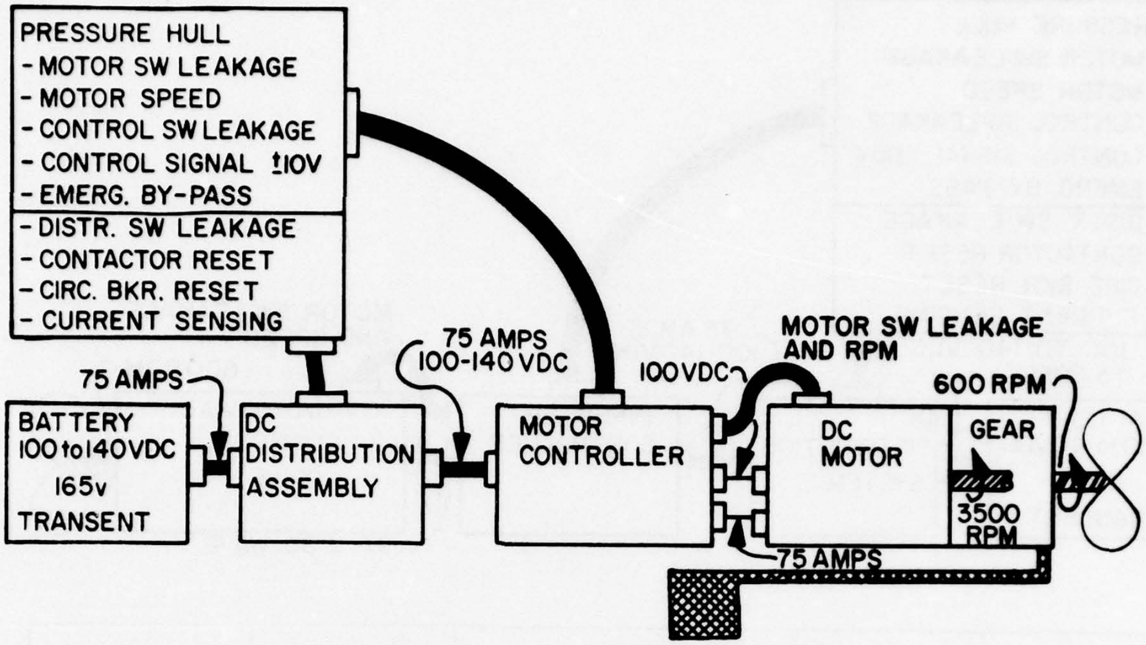
Table I3-2
System 2 - 12-HP Harmonic Drive



Type	400 Cycle 3-Phase	Double Eccentric	3-Blade Propeller
Manufacturer	General Electric	United Shoe	NSRDC (Carderock)
Weight in Air (Filled), lb	200 Estimated for Total Unit		50
Housing Length, in.	16-3/4	14-1/4	
Body Diameter, in.	8-1/2	8-1/2	29
Case Material	316L Stainless Steel	316L Stainless Steel	—
Fluid and Viscosity at 100° F	JP-5 1. 2 cs		
Special Features	Motor and High Speed Portion of Harmonic Drive are Hermetically Sealed and Oil Flooded. Double "Eccentric" "Gear" and Thrust Bearing are Sea-Water Flooded.		Thrust-200 lb Torque-280 lb-ft 140 rpm

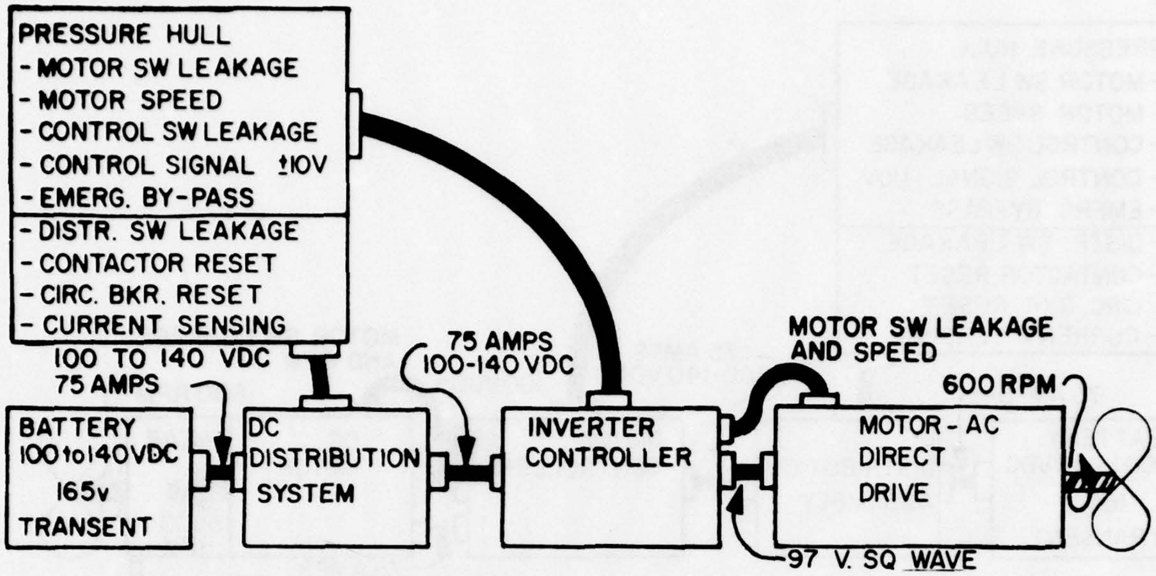
Table I3-3

System 3 - 7 1/2 HP, 100 VDC



Type	Oil-Filled Latching Contactors for Circuit Protection	Oil-Filled Solid-State High Frequency Chopper-Regulator	Neoprene Bladder Secondary Compensator	7-1/2-hp Fluid Filled Series Wound D-C Motor	Dual-Path Fluid-Filled Single Stage Internal Speed Reducer 5.87 to 1 Red.	3-Blade Propeller
Manufacturer	Hartman	J. C. Carter	Tate Engineer	Hoover Electric	Hoover Electric	Michigan Wheel
Weight in Air (Fluid Filled), lb	40 max.	Approx. 50	—	122		24
Housing Length, in.	15 max.	Approx. 11	—	25	6-5/8	
Body Diameter, in.	15 max.	Approx. 12	—	6-1/4	4-7/8	19
Case Material	316 Stainless Steel	Inconel 625	—	316L Stainless Steel	316L Stainless Steel	Bronze
Fluid and Viscosity at 100° F	MIL-S-21568A DC 200 Silicon Oil 0.9 cs	GE Silicon Fluid SF 96-1 cs	Hoover Fluid 2 Hydrocarbon Fluid 5.8 cs			—
Special Features	Current Sensor SW Detector Compensator (Press) Remote Reset	High Ambient Pressure Electronics Compensator (Press) SW Leakage Prop				Thrust 350 lb Torque 66 lb-ft

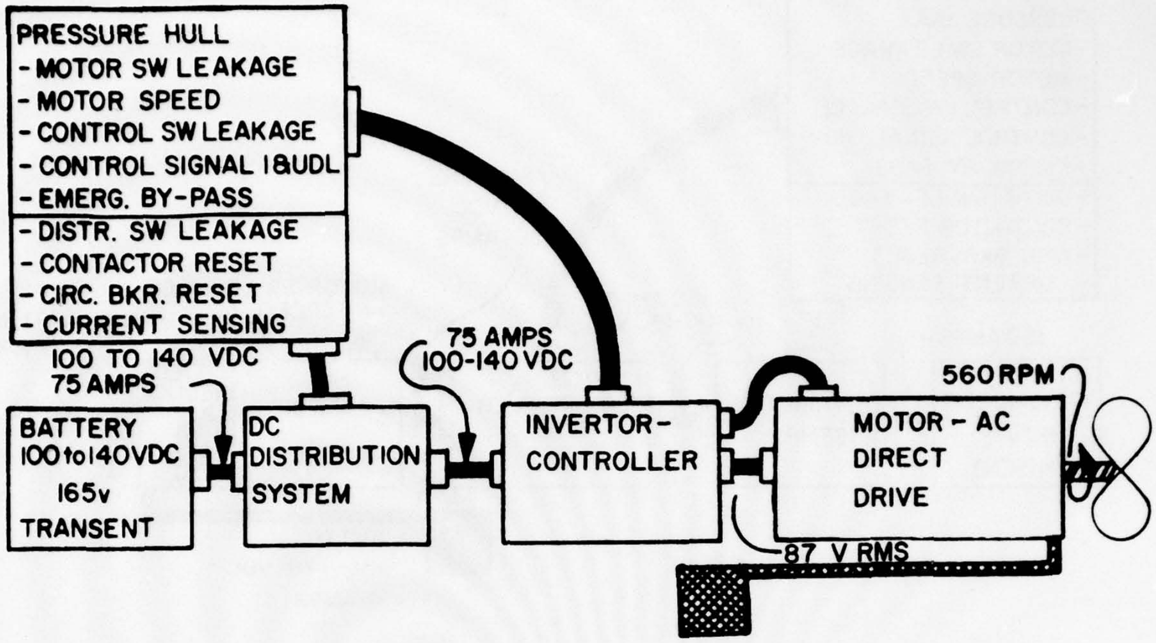
Table I3-5a
System 5A - 7 1/2 HP, A-C, Direct Drive



Type	Oil-Filled Latching Contactors for Circuit Protection	Solid State Oil-Filled High Frequency Chopper Regulator	7-1/2-hp a-c Direct-Drive Motor	3-Blade Propeller
Manufacturer	Hartman	J. C. Carter	J. C. Carter	Michigan Wheel
Weight in Air (Filled), lb	40 max	Approx 50		24
Housing Length, in.	15 max	Approx 11	18	—
Body Diameter, in.	15 max	Approx 12	10.5	19
Case Material	316 Stainless Steel	Inconel 625 3/8-in Thick	Inconel 625	Bronze
Fluid and Viscosity at 100° F	MIL-S-21568A Dow Corning 200 Silicon-Oil 0.9 cs	General Electric Silicon Oil 96-1	Canned Stator with Tellus 15 Oil Sea-Water Flooded	—
Special Features	Current Sensor SW Detector Compensator (Pressure) Remote Reset	High Ambient Pressure Elec. Compensator (Pressure) SW Leakage Probe	Sea-Water Flooded 13000 psi Integrity Pad Type Thrust Bearings	Thrust Approx. 35 lb Torque-66 lb at 7-1/2 hp

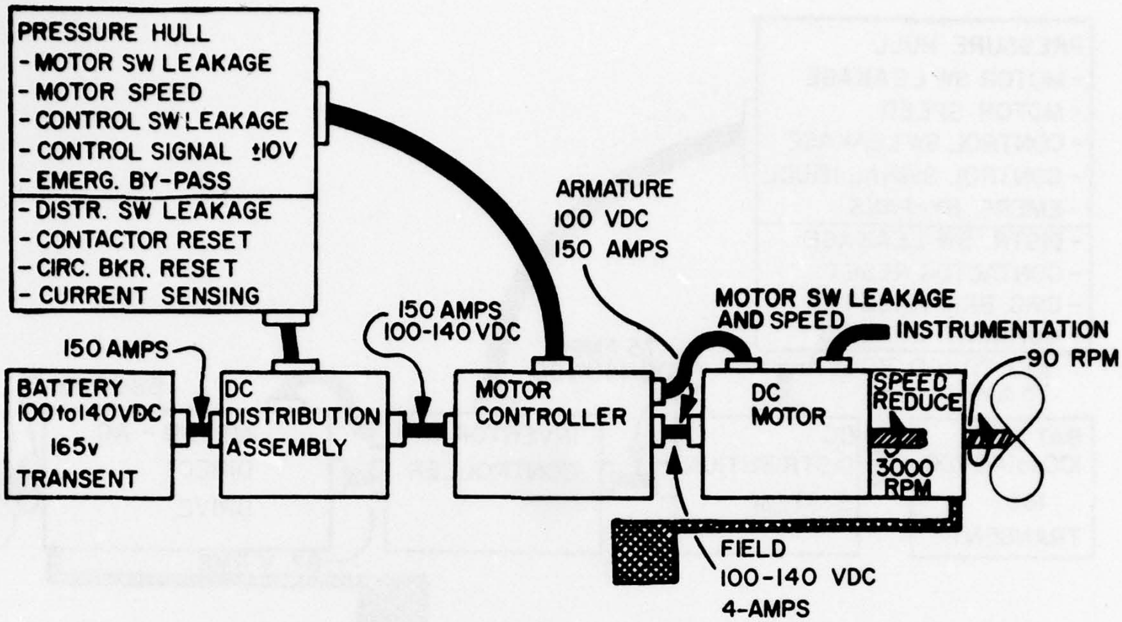
Table I3-5b

System 5B - 7 1/2-HP, A-C, Direct Drive



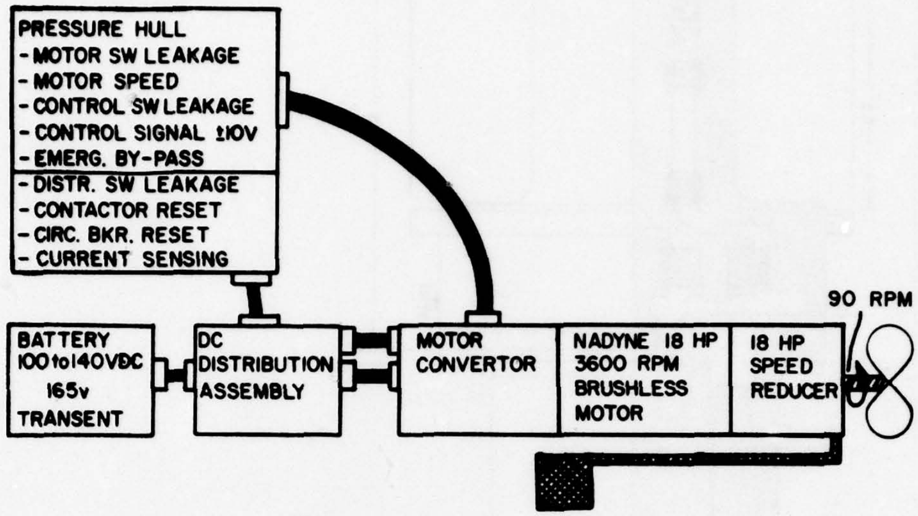
Type	Oil-Filled Latching Contactors for Circuit Protection	Solid State Oil-Filled High Frequency Chopper-Regulator	Neoprene Bladder	7-1/2-hp a-c Fluid-Filled Direct-Drive Motor	3-Blade Propeller
Manufacturer	Hartman	J. C. Carter	Tate Engineering	Franklin Electric	Michigan Wheel
Weight in Air (Filled), lb	40 max	Approx. 50		330	24
Housing Length, in.	15 max	Approx 11		22	
Body Diameter, in.	15 max	Approx 12		9-1/4	19
Case Material	316 Stainless Steel	Inconel 625 3/8-in. Thick		316 Stainless Steel	Bronze
Fluid and Viscosity at 100° F	MIL-S-21568A Dow Corning 200 Silicon Oil 0.9 cs	General Electric Silicon Oil 96-1	MIL-H-5606	MIL-H-5606	
Special Features	Current Sensor SW Detector Compensator (Press) Remote Reset	High Ambient Pressure Elec. Compensator (Press) SW Leakage Probe		Oil-Filled Pressure-Comp.	Thrust Approx. 55 lb Torque-66 lb at 7-1/2 hp

Table I3-6
System 6 - 17 HP DC



Type	Oil-Filled Latching Contractors for Circuit Protection	D-C Chopper (Currently Under Negotiation)	Neoprene Bladder Secondary Compensator	D-C Shunt Wound	Traction Drive	3-Blade Propeller
Manufacturer	Hartman	J. C. Carter or Lear Siegler	Tate Engineering	Lear Siegler Power Equip. Division	New Departure Hyatt Bearings	Michigan Wheel
Weight Air (Filled), lb	40 Max			100	150	200
Housing Length, in.	15 Max			26	11	—
Body Diameter, in.	15 Max			6.1	10	66
Case Material	316 Stainless Steel		Neoprene	316 Stainless Steel	316 Stainless Steel	Aluminum
Fluid Viscosity at 100° F	MIL-S-21568A Silicon Oil 0.9 cs		MIL-H-5606 14.4 cs	MIL-H-5606 14.4 cs	MIL-H-5606 14.4 cs	
Special Features	Current Sensor SW Detector Compensator (Press) Remote Reset			Propietary Brush Compensation System Centrifugal Filter 3.2 L/D Ratio Instrumentation Connector	Low Noise Smooth Torque Transmission Vibration Free Compound Planetary	Thrust 1200 Torque 875 ft-lb at 17 hp

Table I3-7
System 7 - 18 HP, Brushless, DC (NADYNE)



Type	Oil-Filled Latching Contractors for Circuit Protection	Neoprene Bladder Secondary Compensator	Solid State Converter -Variable Freq. -Variable Voltage	3-phase, 3600 rpm 6 Pole, 60 H_2	Compound Planetary Gear	3-Blade Propeller
Manufacturer	Hartman	Tate Engineering	North J. C. Carter Subcontractor	American	Rockwell	Michigan Wheel
Weight in Air (Fluid Filled), lb	40 Max	—	50 (Est)	200	275	200
Body Diameter and Length, in.	15 Max 15 Max	— —	11.3 21	11.3 15.3	11 34	66 —
Case Material	316 Stainless Steel	Neoprene	321 CRES PL	321 CRES PL	321 CRES PL	Aluminum
Fluid and Viscosity at 100° F	MIL-S-21568A D-C 200 Silicone Oil 0.9 cs	—	GE SF-1143 Silicone Oil 1 cs	GE SF-1143 Silicone Oil 1 cs	GE SF-1143 Silicone Oil 1 cs	
Special Features and Advantages	Current Sensor SW Detector Compensator (Press) Remote Reset	—	400 Ampere Current Unit	Speed-Torque Charact. Like D-C Shunt Motor Solid Rotor Electronic Commutation Troller High Efficiency Near Unity Power Factor	Special Design for 1 cs Fluid	Thrust 1200 lb Torque 875 lb-ft

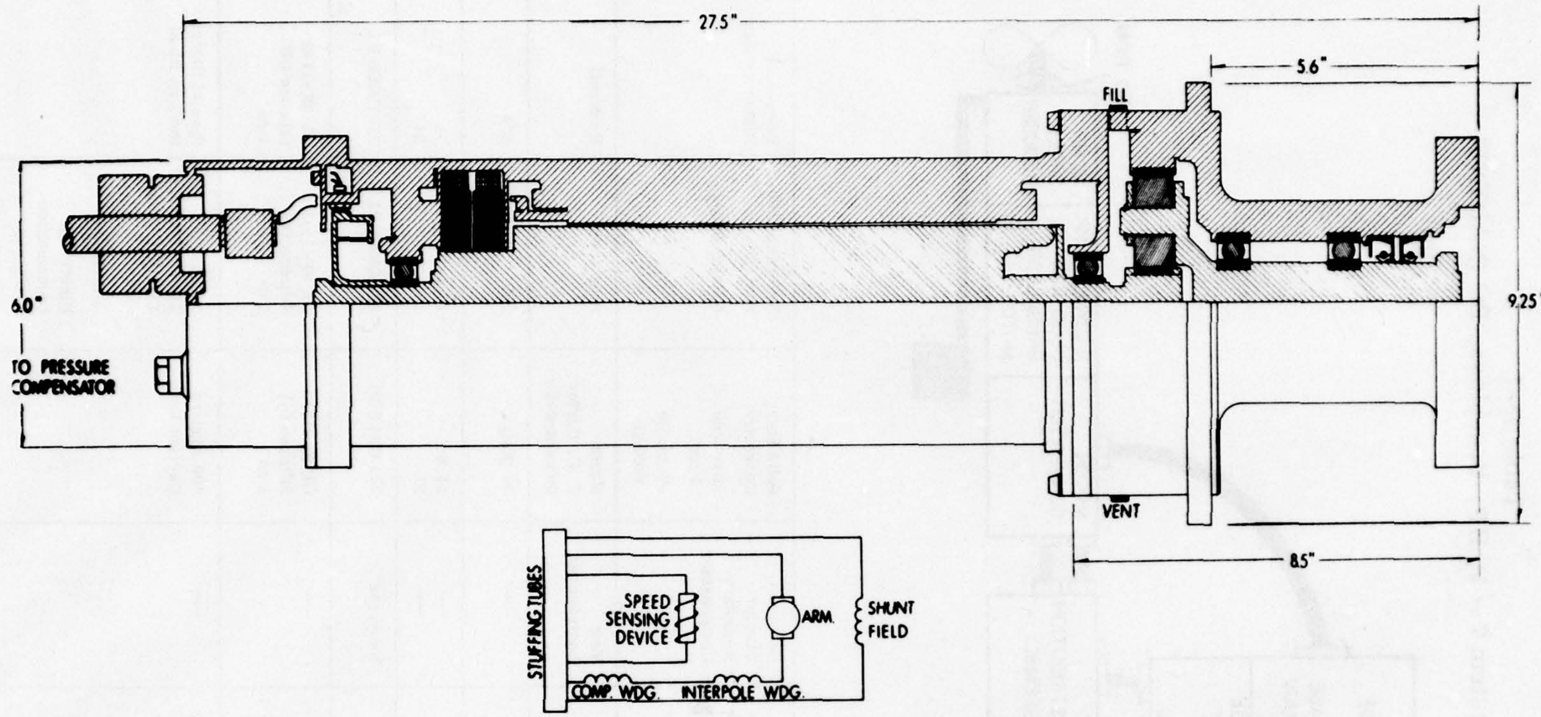


Figure I3-1
17-HP D-C Motor and Speed Reducer Gear Assembly

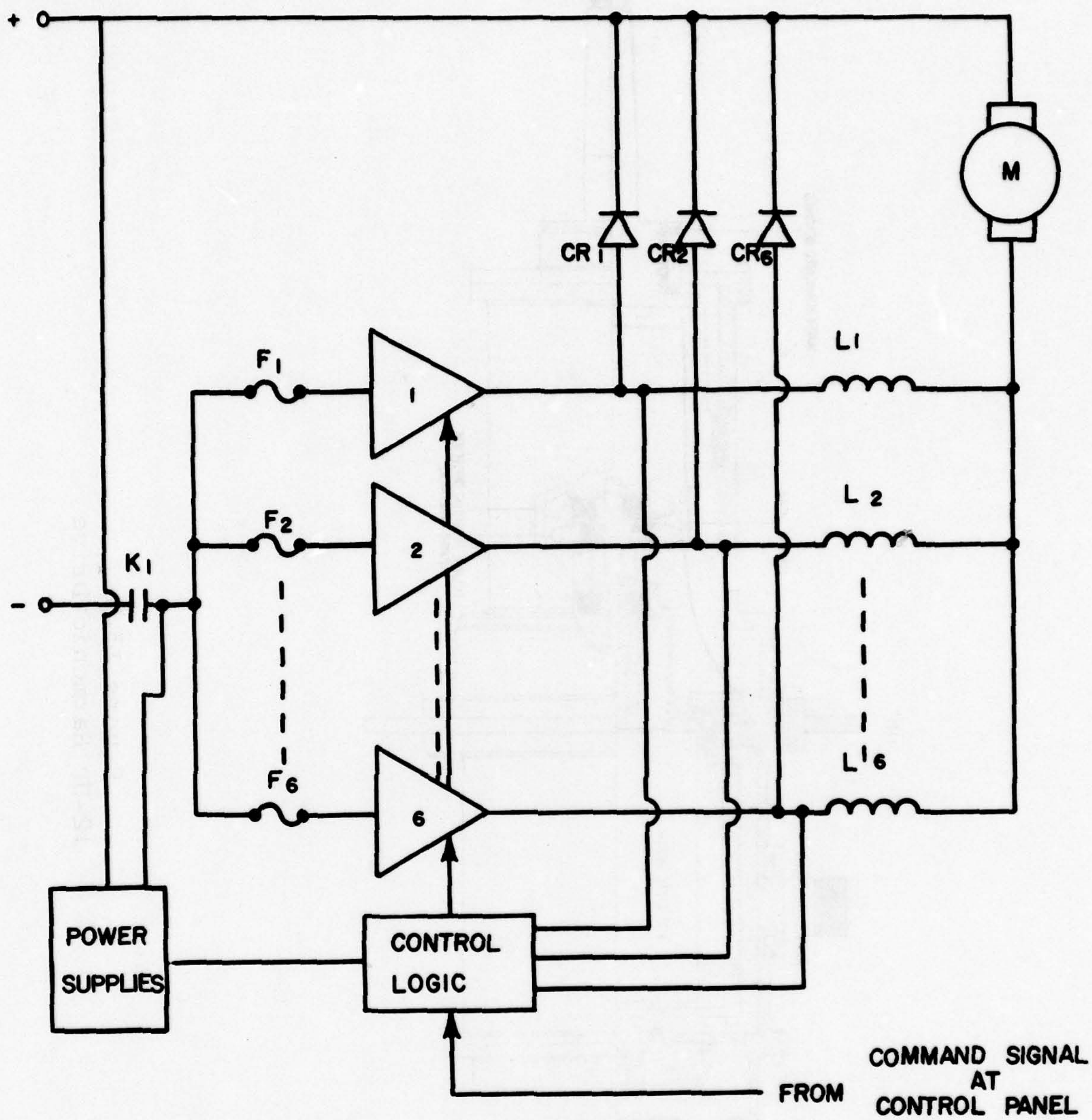


Figure I3-2

Connection of Six Modules for Armature Current Control

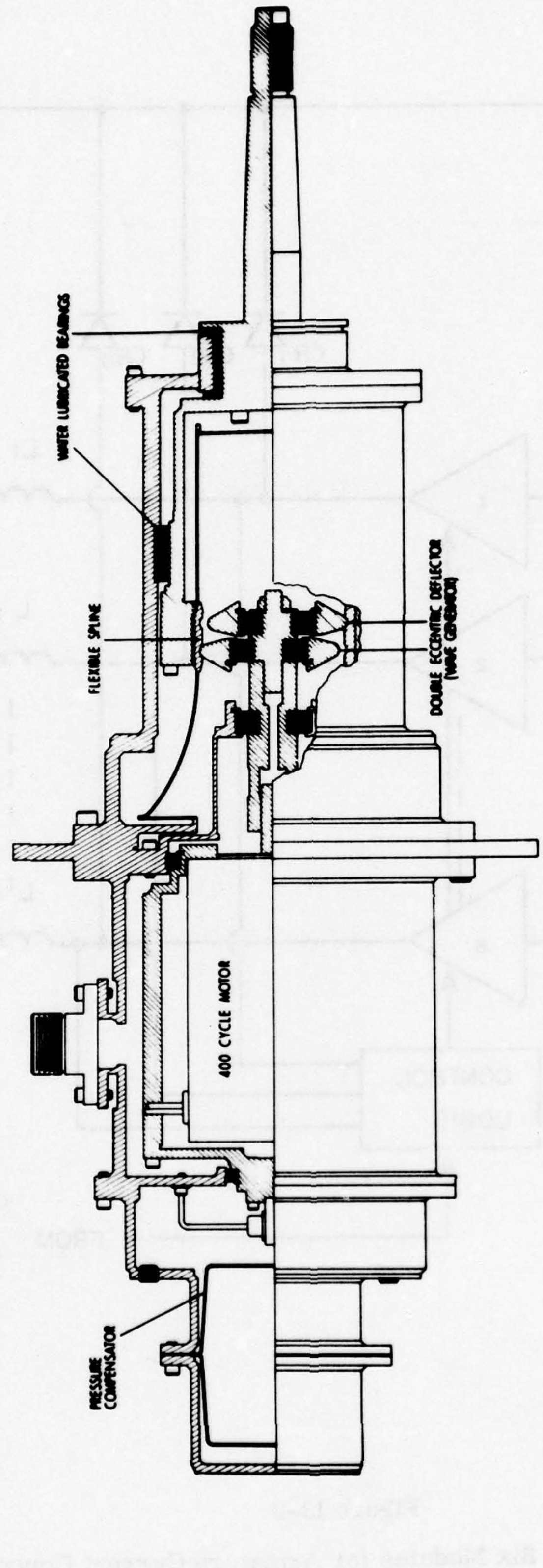


Figure I3-3
12-HP Harmonic Drive

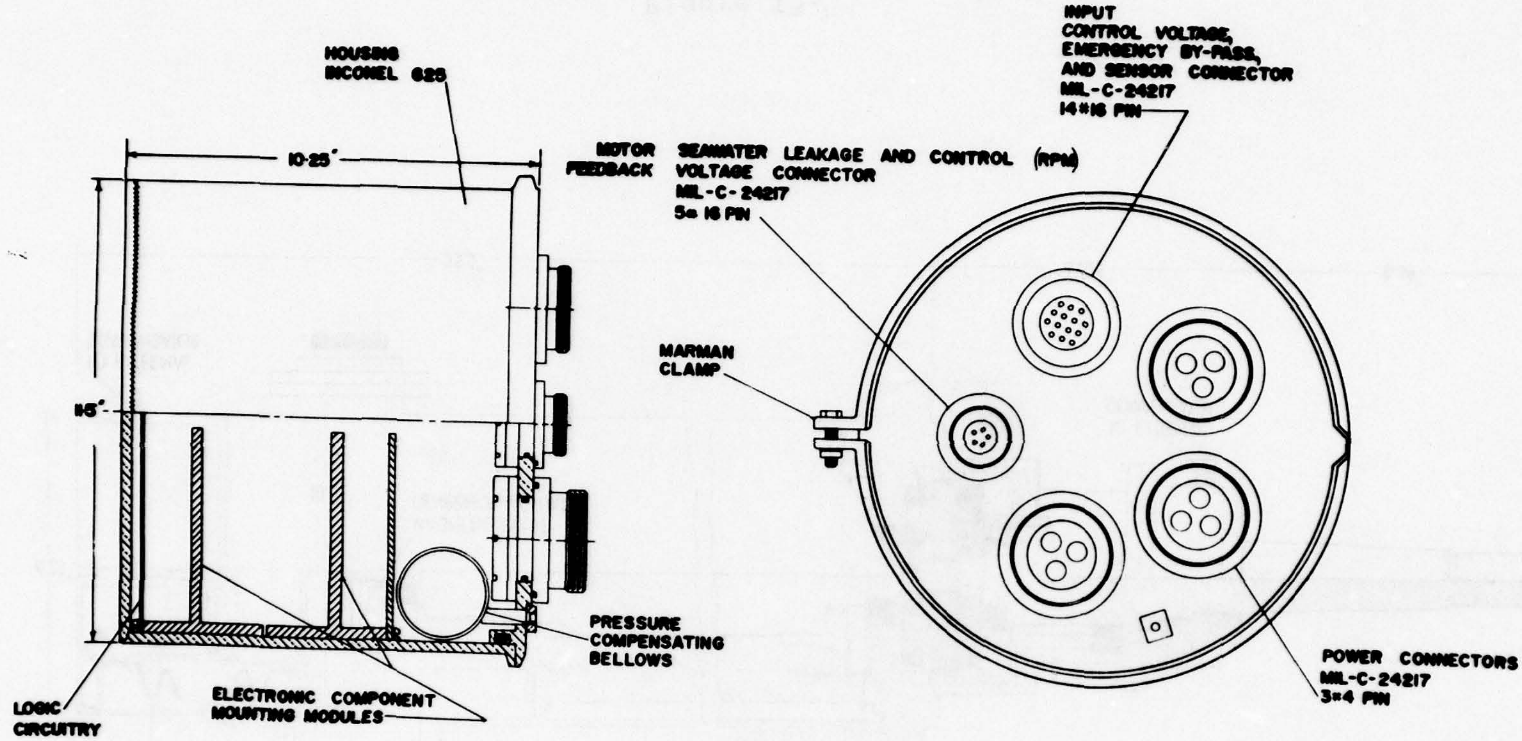


Figure 13-4
D-C Motor Controller

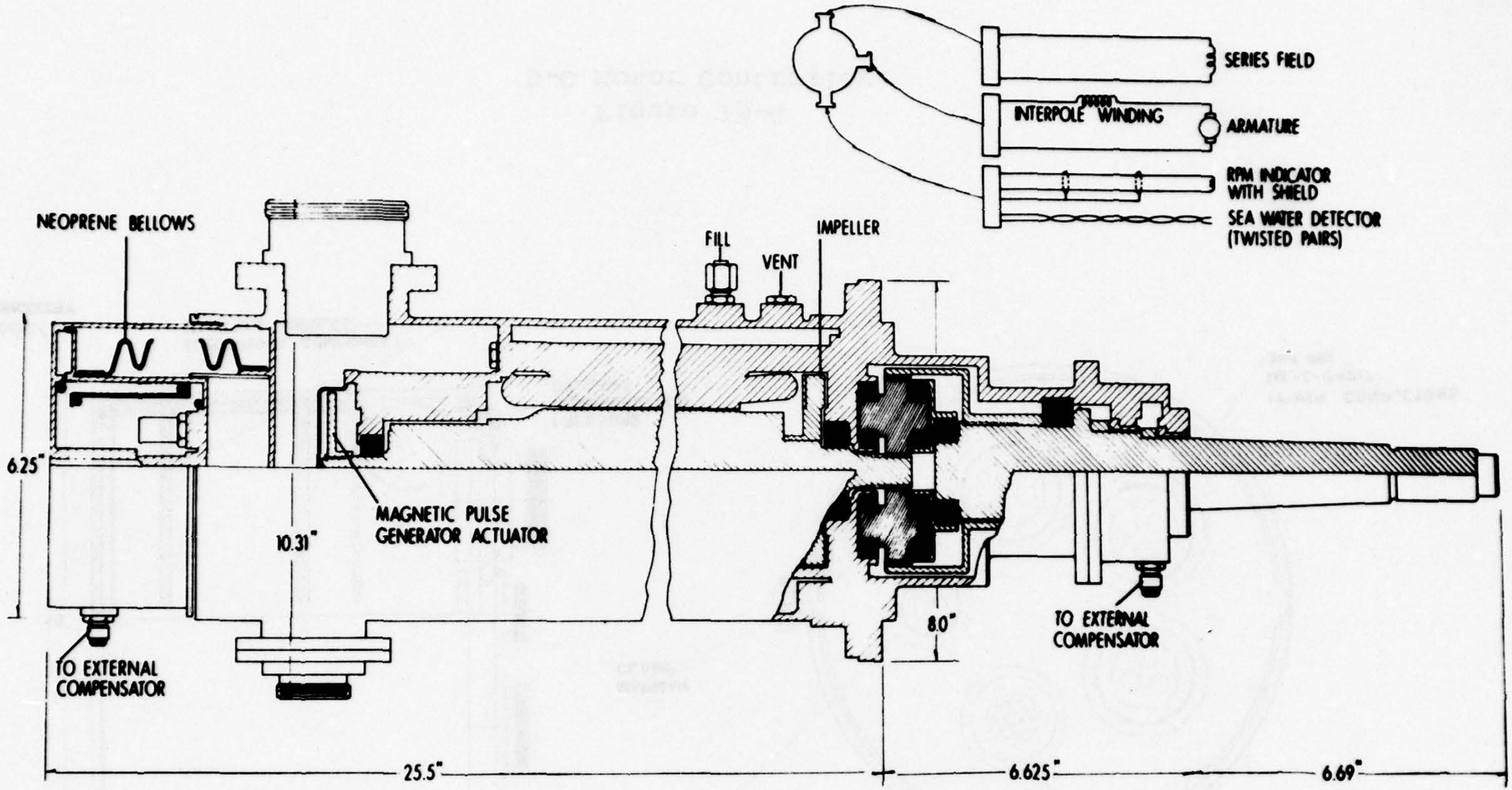


Figure I3-5
7 1/2-HP D-C Motor and Speed Reducer Assembly

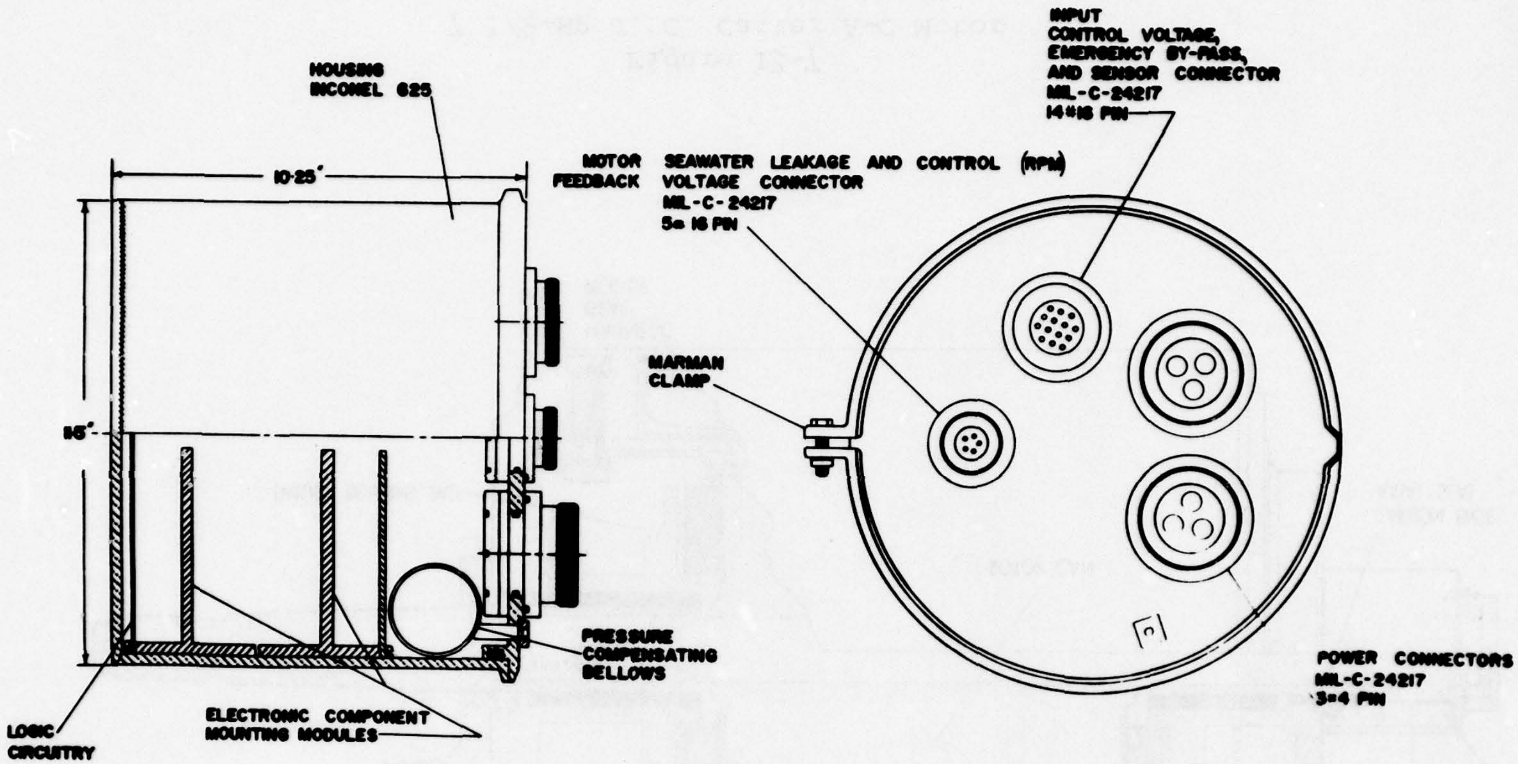


Figure I3-6
Inverter-Controller

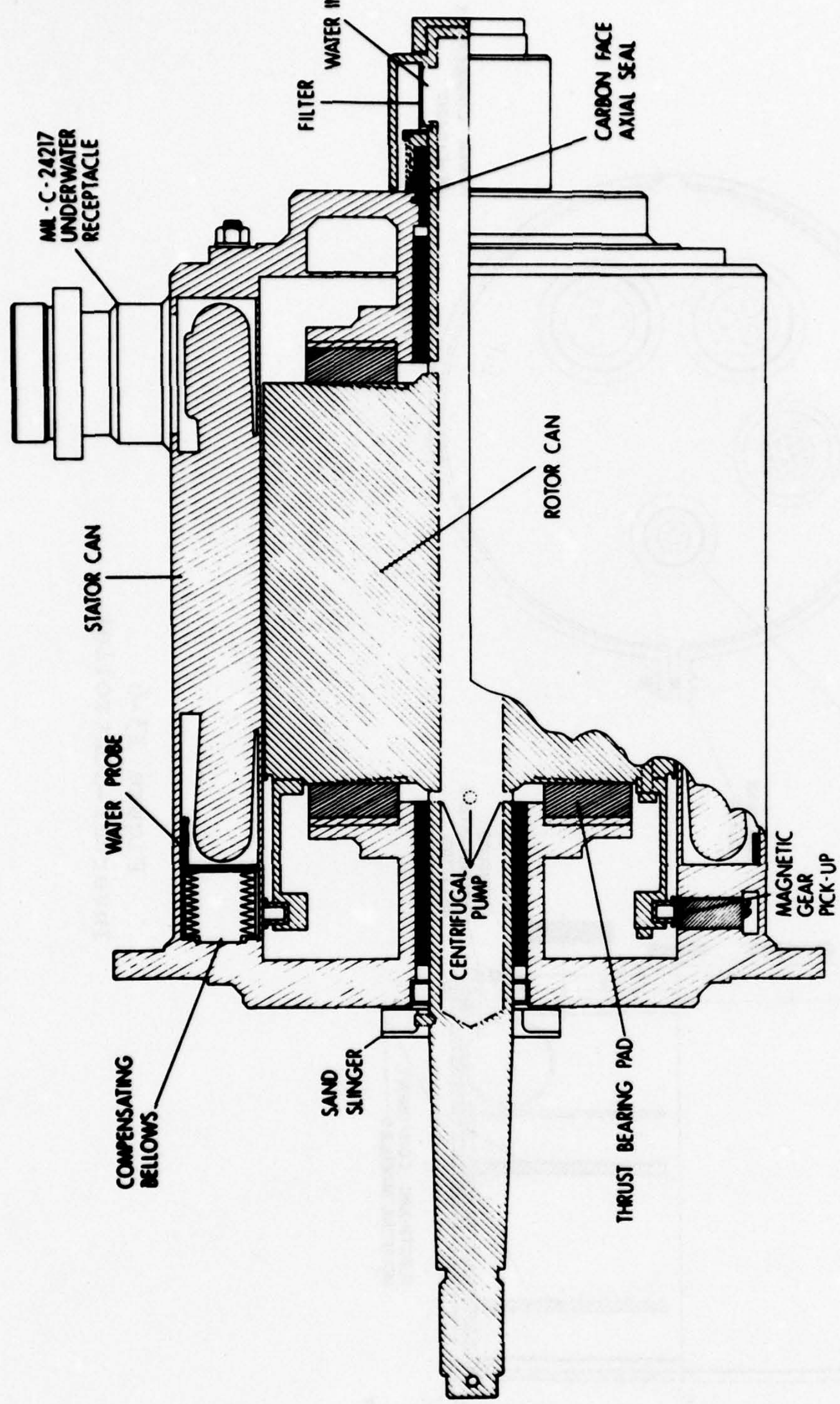


Figure I3-7
7 1/2-HP J. C. Carter A-C Motor

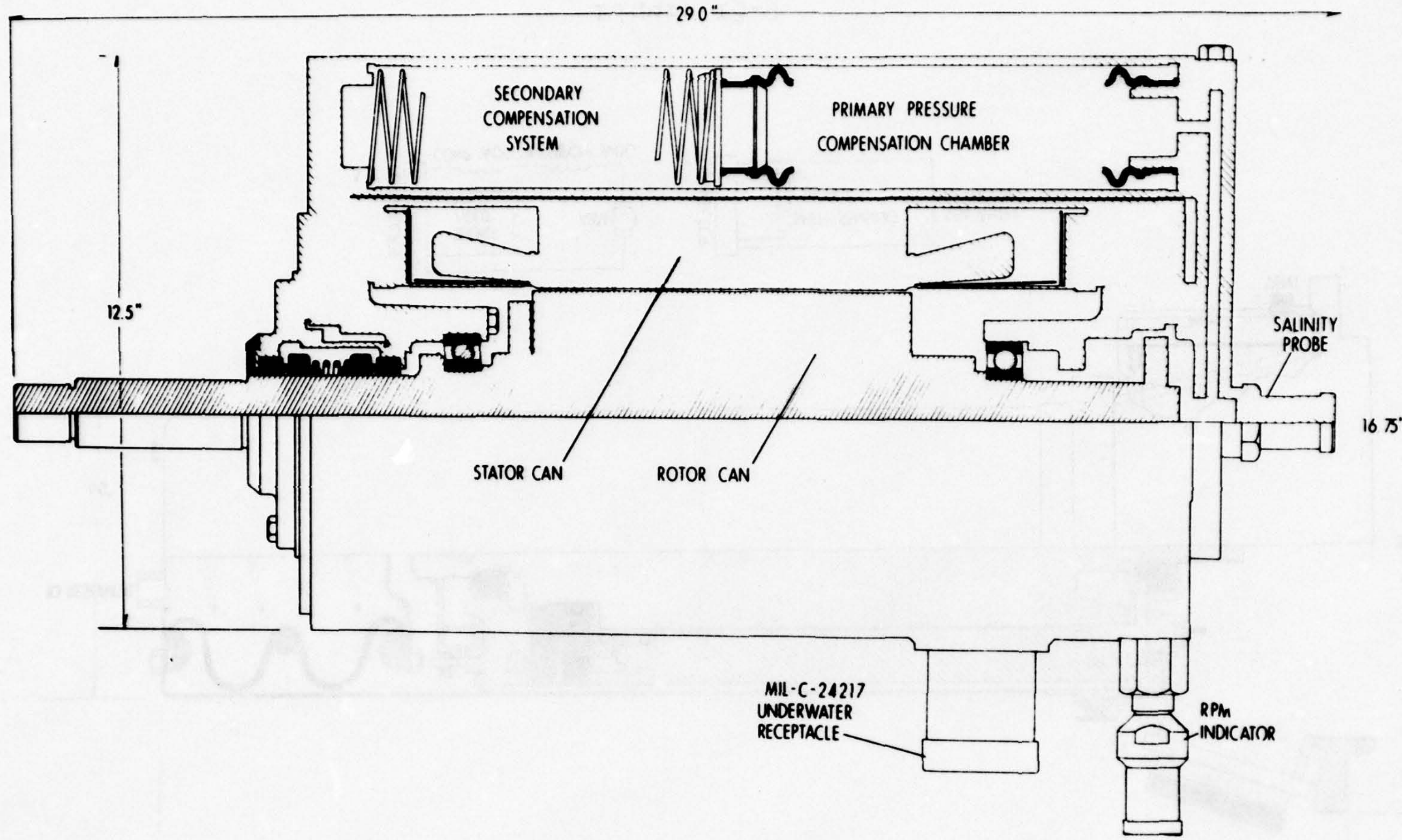


Figure I3-8
7 1/2-HP Franklin Electric A-C Motor

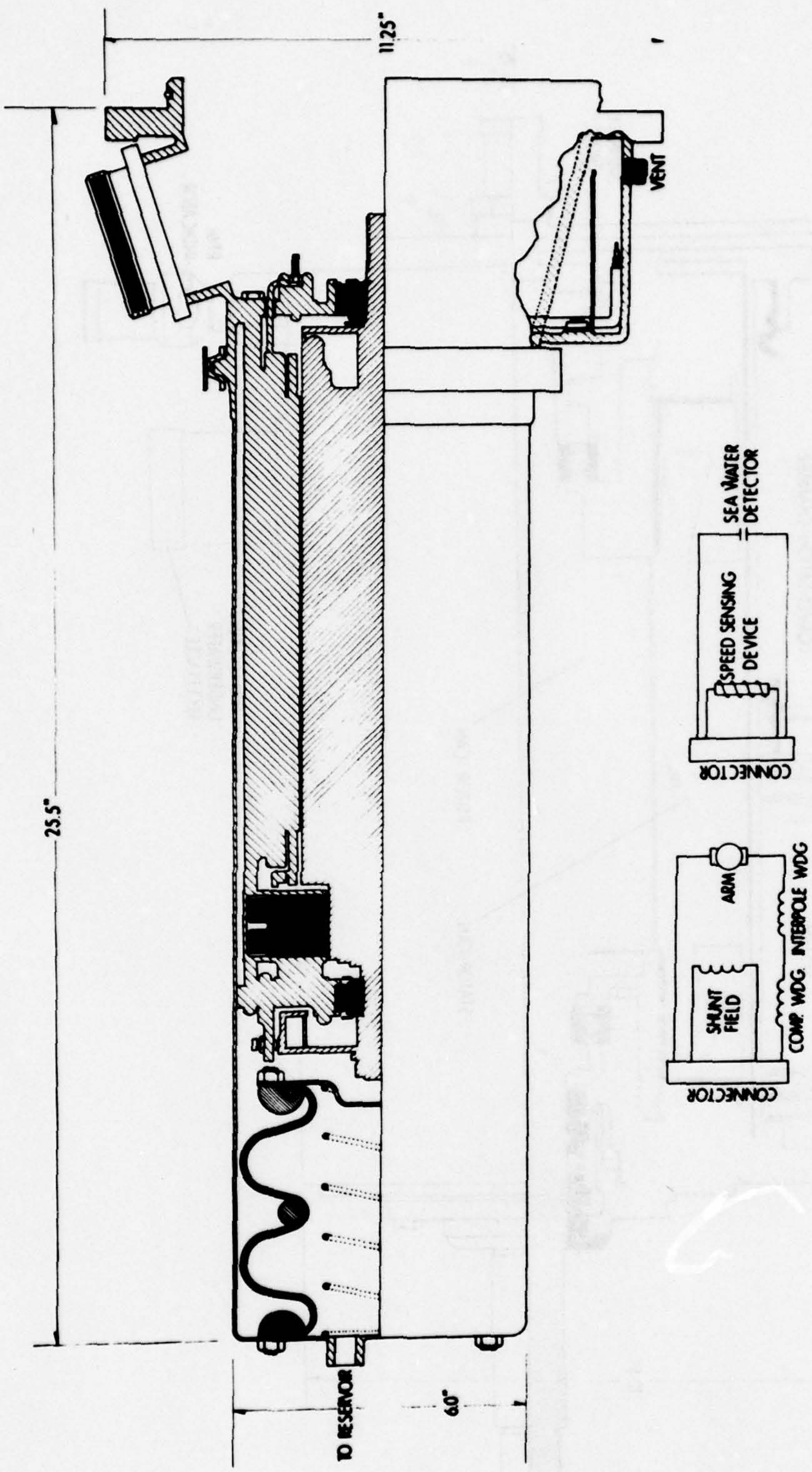


Figure I3-9
17-HP D-C Motor

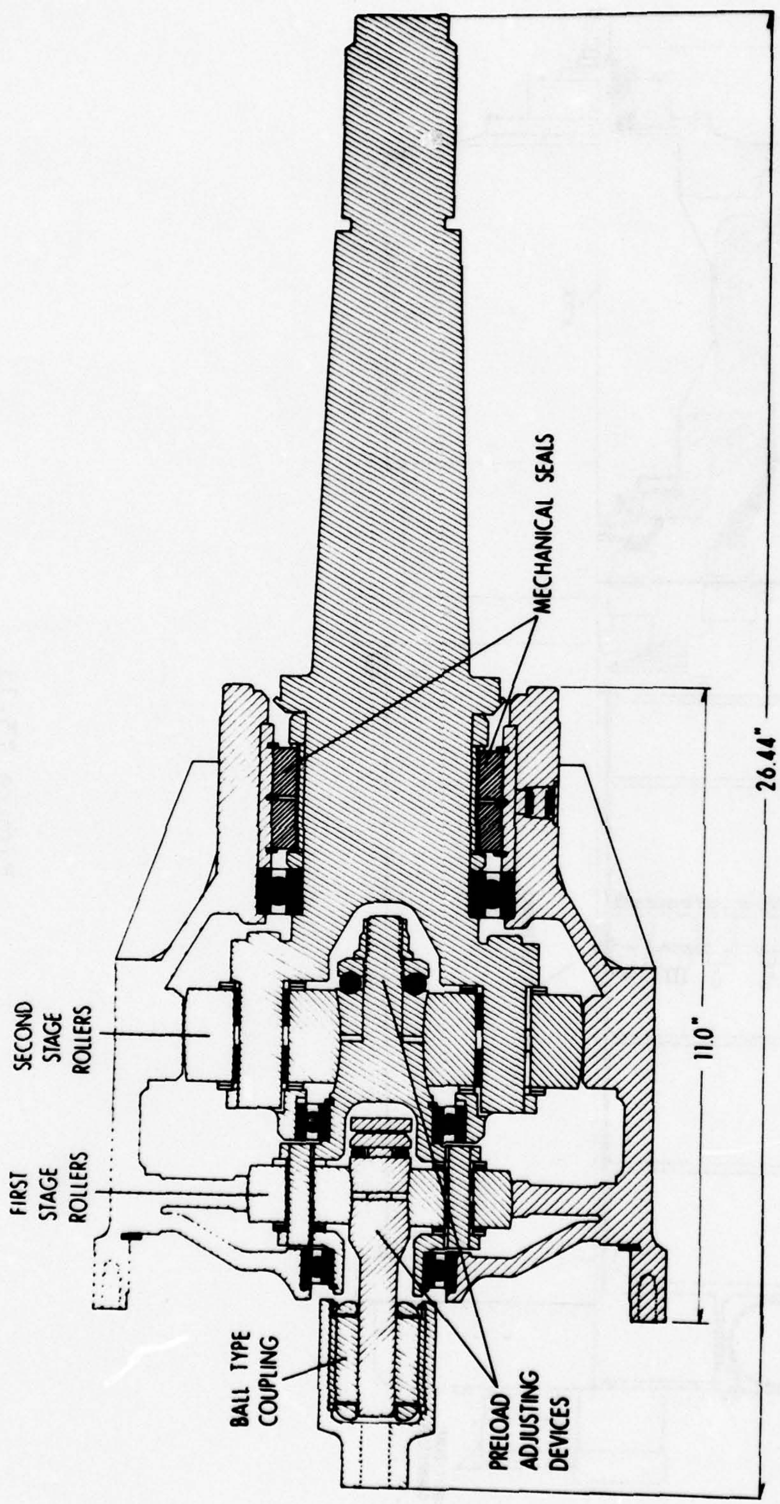


Figure I3-10
Traction Drive

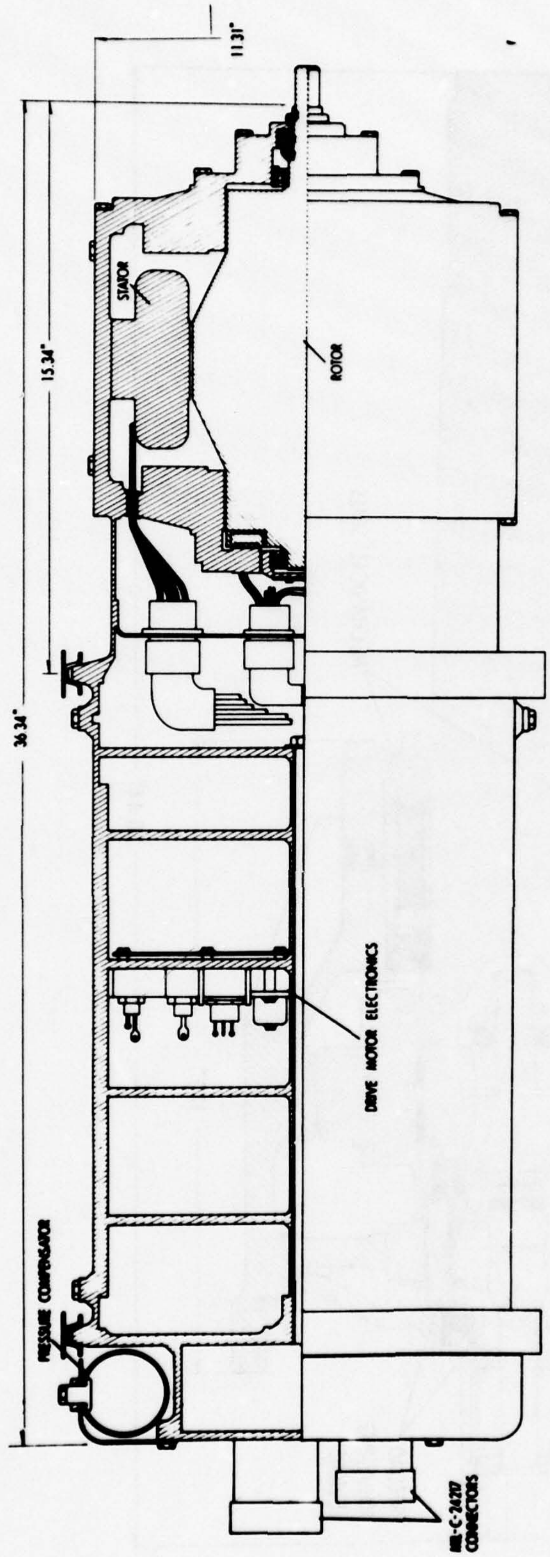


Figure I3-11
18-HP Nadyne Motor

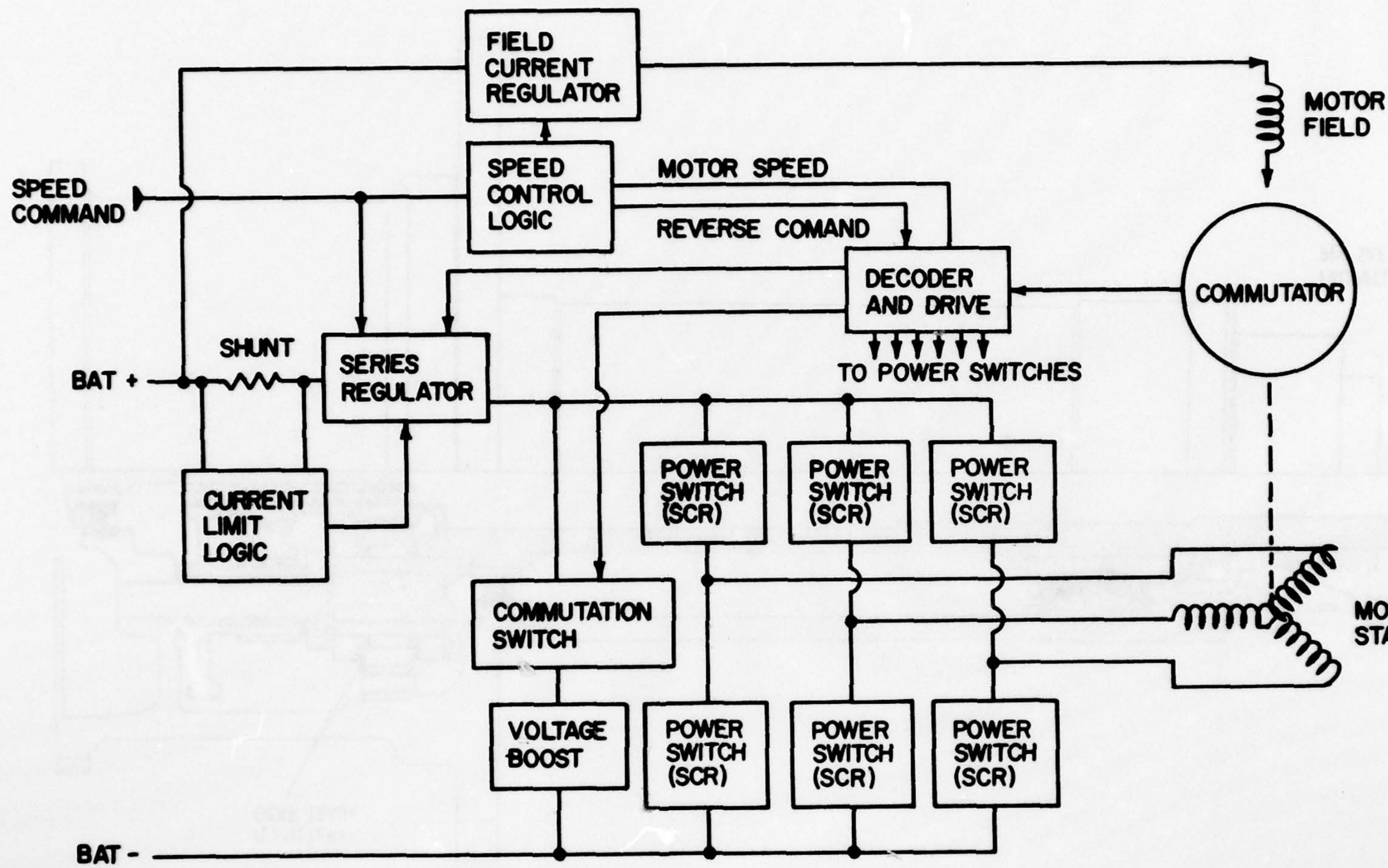


Figure I3-12

Controller - Block Diagram

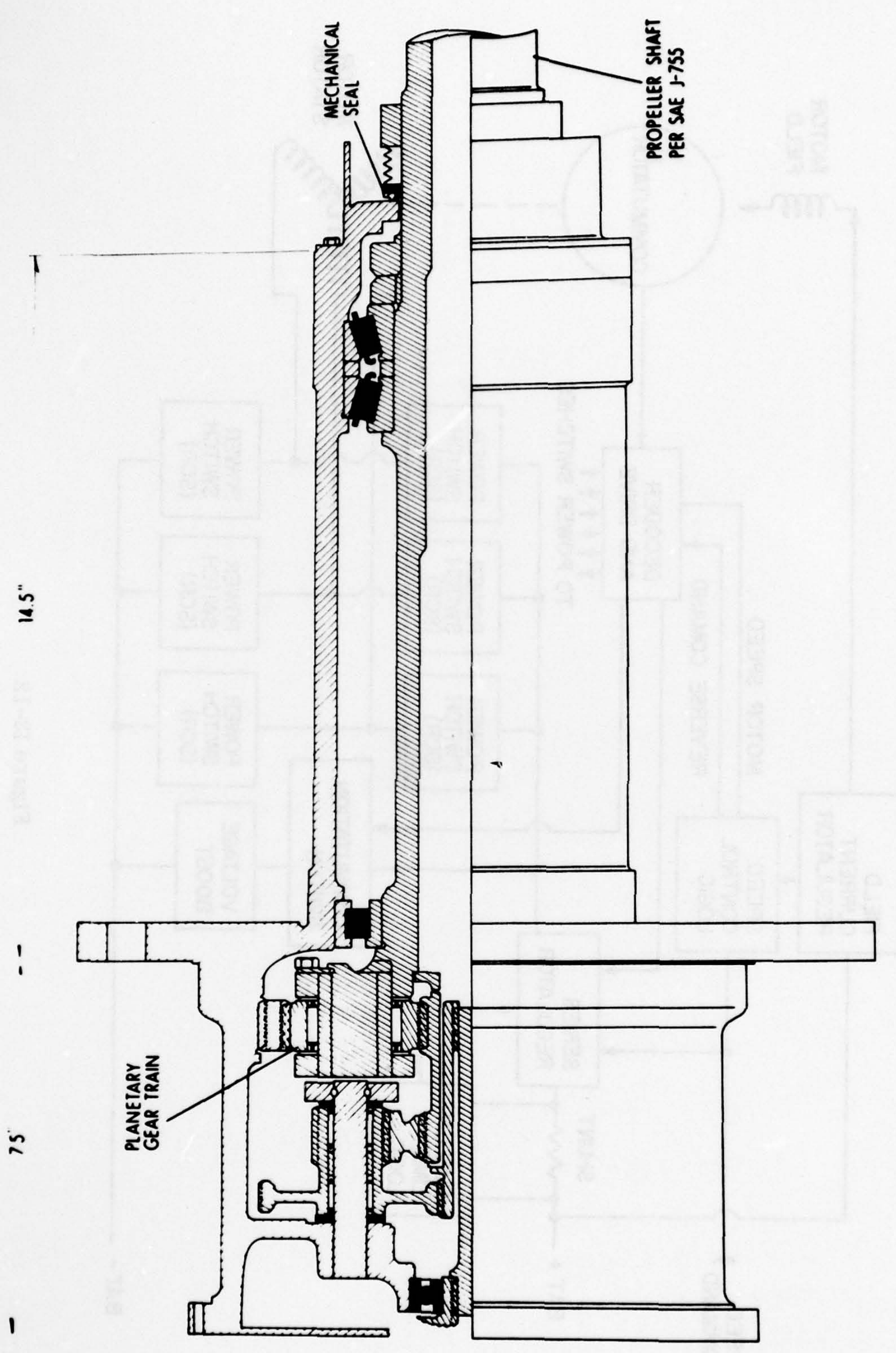


Figure I3-13
Speed Reducer Assembly

PART B

GENERAL TEST DESCRIPTION

1.0 BENCH TESTS

Objective: To determine the initial condition, the operational characteristics, and the condition after environmental testing of components and drive systems.

1.0.1 Bench Test Facility—This facility is to be used primarily to determine the performance characteristics of components under steady state and transient loading conditions at various speeds and ambient temperatures.

Figure I3-14 shows the facility as it will be used for evaluating speed reducers. A speed reducer is being driven by a motoring dynamometer. Propeller torque loadings are simulated by an eddy current brake and propeller thrust loadings by a thrust cylinder. Ambient water temperature may be maintained at any desired level, and the performance of the component can be determined for any desired speed and loading condition.

The assembled drive system is to be evaluated in a similar manner. This is to be done to "check out" the complete assembly prior to and after pressure and propeller loaded life tests. The heat generation characteristic of each assembly at various loads and speeds will also be determined.

Instrumentation for tests will be similar for bench, shallow submergence, and deep submergence tests. It will consist basically of a high-impedance isolation amplifier on a per channel basis, which in addition to providing amplification will isolate sensing transducers and sensing points from recording system ground points. Each channel amplifier will provide three outputs. Output 1 will be applied to an analog magnetic tape recorder for complete data preservation. Output 2 will be applied to a high-level alarm system which will, at the operator's discretion, sound an alarm or sound an alarm and kill power to the test unit. Output 3 will be applied to either an oscillographic recorder or a multichannel sampling oscilloscope for quick-look observations.

For purposes of data correlation, a time code generator will supply day, hours, minutes in decimal display to operator, coded information to magnetic tape recorder and binary coded decimal information to the oscillograph. Preservation of data on magnetic tape will allow for recalling specific time intervals of data for more detailed analysis as an off-line option.

1.1 D-C Distribution Assembly

1.1.1 Initial Inspection—Photograph each unit; measure critical dimensions; weigh each unit empty and oil filled; check electrical continuity, leakage, and dielectric

potential; perform fluid analysis; check sea-water leakage detector and fluid pressure compensator position.

1.1.2 Operational Characteristics—Operate contactors and circuit breaker reset coils on 21 and 29 vdc; calibrate current shunt; determine fluid compensator position at 40° and 85° F; measure contact drop, arc duration, bounce, clearance, and temperature rise.

1.1.3 Periodic Inspection—Photograph; check sea-water leakage detector and fluid pressure compensator position; measure electrical continuity, leakage, dielectric potential, and weight. If indicated, remove the fluid and analyze it.

1.2 D-C Motor Controller

1.2.1 Initial Inspection—Per 1.1.1.

1.2.2 Operational Characteristics—Short circuit test to check the current limit feature. Zero control voltage will be applied to verify the requirement for a 5% maximum input current from the power source. Determine the effects of varying input voltage on the open circuit output voltage.

1.2.3 Periodic Inspection—Per 1.1.3.

1.3 A-C Inverter-Controller—Per 1.2 except a-c measured instead of d-c.

1.4 D-C Motor

1.4.1 Initial Inspection—Per 1.1.1. Measure brush length; photograph the commutator, radial runout, bar-to-bar variation of commutator, and brush spring force.

1.4.2 Operational Characteristics—With the motor fitted with a special shaft seal if needed, drive it with the dynamometer and measure torque, generated current and voltage, and bearing noise, as a function of rpm under the following conditions:

a. Fluid removed, brushes removed.

b. Fluid removed, brushes in, machine open circuit.

c. Fluid filled at temperatures of 40° and 85° F, brushes removed, machine open circuit.

d. Fluid filled at temperatures of 40° and 85° F, brushes in machine open circuit.

e. Fluid filled at a temperature 40° F, brushes in, machine short circuited (current not exceeding 200% rated).

Operating the machine as a motor with cooling water at 40° F, measure speed-torque-efficiency, speed regulation, and brush voltage ripple over the operating speed range.

With cooling water at 85° F, make a heat balance test at rated load and speed, noting fluid compensation position. With cooling water at 40° F, run at rated load and speed for 20 hours to determine brush wear rates.

1.4.3 Periodic Inspection—Per 1.4.1 and 1.4.2 except all cooling water temperatures 40° F. Measure speed torque-efficiency only at rated conditions and omit heat balance and 20-hour run.

1.5 <u>A-C Motor</u>

1.5.1 Initial Inspection—Per 1.1.1 and measure copper resistance of stator.

1.5.2 Operational Characteristics—Driving the machine with the dynamometer, measure torque, generated current and voltage, and bearing noise, as a function of rpm under the following conditions:

a. Fluid removed, machine open circuit.

b. Fluid filled, at temperatures of 40° and 85° F, machine open circuit.

c. Fluid filled, at a temperature of 40° F, machine short circuited (current not exceeding 200% rated).

Machine will not be operated as a motor independent of the inverter-controller except in factory tests.

1.5.3 Periodic Inspection—Per 1.1.1 and 1.5.2 except at 40° F only.

1.6 <u>Speed Reducer</u>

1.6.1 Initial Inspection—Photograph; measure critical dimensions and weight (empty).

1.6.2 Operational Characteristics—With the speed reducer fitted with a special oil seal, and with the dynamometer driving, and the eddy current brake and thrust simulator loading, measure backlash, speed-torque-efficiency, and noise over the operating range at oil temperatures from 40° and 140° F.

With oil removed, make no-load, no-thrust, torque measurements as a function of speed.

1.6.3 Periodic Inspection—Repeat 1.6.2.

1.7 Drive System

1.7.1 Initial Inspection after Assembly—Photograph, fill, bleed, and check compensator position on fluid systems as required. Sample and analyze fluids. Weigh total system. Check electrical continuity, leakage, and high potential. Check sea-water leakage detectors.

1.7.2 Operational Characteristics—Measure speed-torque-efficiency characteristics, dead band, speed linearity, and speed regulation up to maximum torque and thrust capability in both directions of rotation and at cooling water temperatures of 40° and 85° F, measuring inputs to the system and inputs to the motor, including all waveforms, phase angles or slip frequencies voltages, currents, etc.

With a cooling water temperature of 85° F and an input voltage of 115 vdc, heat balance test at rated load and speed, noting the position of all pressure compensators.

Immediately following this, make a rapid-reversal test, consisting of 60 reversals from full load forward to full load reverse and return in 30 minutes, followed by 1-hour steady-state operation at rated load.

1.7.3 Periodic Inspection—Repeat 1.7.1 and measure speed-torque-efficiency at rated load and 40° F water temperature. Then make periodic inspection of all components.

2.0 ENVIRONMENTAL SYSTEM TESTS—Submersible Electric Drives

Objective: The environmental tests will be performed to determine the system characteristics and operational suitability for use in deep ocean vehicles. The testing to be conducted in both the shallow water facility and the pressure facility will progress from those tests considered least severe on system components to those considered most harsh. Testing will be conducted in this manner to ensure that some data will be available for system evaluation in the event of a failure in a more severe test.

2.1.0 Shallow Submergence Test

2.1.1 Shallow Water Test Facility—See Figure I3-15. This test facility will be used to evaluate electro-mechanical drive systems. The test platform to which the equipment is fixed is situated about 20 feet from the seawall, at which point the depth of the river is over 30 feet. A dolly and monorail-hoist are provided to transport the system hardware and to raise and lower the test platform. All systems will be mounted to the test platform and loaded by a propeller. A portable control and instrumentation room is situated between the test platform well and seawall.

a. Heat Balance Test—A heat balance test will be conducted at 100 and 140 volts d-c input and at rated load for the system when loaded by a propeller. During this test, instrumentation will be used to check and insure proper operation.

b. Speed-Torque and Noise Tests—No load tests, with the propeller removed, and the system immersed in the river water, will be made at 100 and 140 volts d-c input over the controllable speed range in the forward and reverse directions. No load losses and waterborne noise will be measured as a function of speed. In addition, special measurements of waterborne noise from individual components will be made by raising all other components above the water level.

Propeller loaded tests will be made at 100 and 140 volts d-c input over the controllable speed range in both directions of rotation. Speed-torque-efficiency characteristics and thrust and waterborne noise measurements will be made.

c. Life and Response Tests

(1) Fifty hours, 3/4 load, steady state, in one direction of rotation.

(2) Same as (1) but in opposite direction of rotation.

(3) Acceleration test: From standing start upon application of + 10 vdc control signal (2 runs). Requirement:

0 - 75% rated speed - 0.5 sec max.
0 - 95% rated speed - 1.5 sec max.

(4) Reversal test: From rated speed forward to 75% full reverse speed from time of control signal change from +10 to -10 vdc. Requirement: 1.3 sec max (test to be run twice).

(5) One-hundred-hour rated load, steady state, in one direction of rotation.

(6) Same as (5) but in opposite direction of rotation.

(7) Two hundred hours under varying conditions of direction of rotation and loading. Test will include predetermined periodic shutdowns of sixteen to 24 hours to evaluate corrosive action of noncirculatory water on system components.

(8) The concluding test will consist of six reversal cycles under following conditions:

Rapid Reversals—From full load forward to full load reverse and return. Each cycle to consist of 60 reversals (two per min) with one hour steady state operations at the end of the 60 reversals.

d. Other Testing

(1) Inclined operation.

(2) Shock.

(3) Vibration.

(4) 165 vdc transient.

2.2.0 Pressure Simulation Tests

2.2.1 Pressure Test Facility—See Figures I3-16 and I3-17. The drive system will be tested in a 4000 psi pressure tank, filled with simulated seawater made from a sea salt mix (ASTM D-1141-52, Formula A). A 50 gpm, 5-hp deep-well casing pump capable of operation in a 4000 psi ambient pressure environment will circulate the water through a shell-in-tube, 10,000 psi glycol-sea-water heat exchanger. The water will be maintained at a temperature of 40° F. The drive system will be loaded by means of a Racine hydraulic gear pump. Torque load will appear as heat in the oil circulated by the pump through a reducing valve and will be rejected through a shell-in-tube, oil-freshwater heat exchanger. The loading system will be adjusted so that the torque vs speed points approximate the specified propeller loading curves, Figures I3-18 and I3-19 for the system under test.

2.2.2 Pressure Test Procedure

a. Heat Balance Test—A heat balance test will be conducted at rated output of the system to determine equilibrium temperature rise (above water temperature) at 100 + 140 vdc input at 4000 psi ambient and water temperature of 40° F.

b. Life and Dive Tests

(1) 50-hour steady state test at 3/4 load and 90% rated speed with the drive system operating in one direction of rotation. Nominal voltage to controller, 120 vdc. 4000 psi and 40° F ambient.

(2) 50-hour steady state test at 3/4 load and 90% rated speed operating with the direction of rotation reversed from that of Test (1). Nominal voltage to the controller, 120 vdc. 4000 psi and 40° F ambient.

(3) Simulated Mission Test—In seawater at a temperature of 40° F and a pressure of 0 psig, the drive system will be operated at half load (approx 70% rated speed). The sea-water pressure will then be increased to 4000 psig at a rate of 200 psi per min. At this pressure, the drive will be subjected to rapid reversals from rated load and speed forward, to rated load and speed in the reverse direction and return; a total of 60 times in a period of 30 minutes. Next, the drive will be operated

at rated load and speed for 1 hour after which it will be operated at various combinations of loads, speeds, and directions of rotation for 4 hours more. Then with the drive at half load (approx 70% rated speed), the ambient sea-water pressure will be reduced to 0 psig at the rate of 200 psi per min. The drive will be deenergized and allowed to stand in the 40° F seawater for 16 hours. This complete procedure will again be repeated twice, giving a total of three simulated dives, after which the drive components will be inspected mechanically and electrically.

(4) Slow Pressure Cycling

(a) 25-hour steady state operation at 3/4 load with pressure being cycled from 0 to 4000 psig at 1/2 cycle per hr. Water temperature maintained at 40° F. Nominal voltage, 120 vdc.

(b) 25-hour steady state operation at 3/4 load with conditions the same as (4)(a) except that the drive system will be operated in the opposite direction of rotation.

(c) 50-hour steady state operation at rated load with water temperature at 40° F and pressure being cycled from 0 to 4000 psi at the rate of 1/2 cycle per hr., 25 hours in one direction of rotation and 25 hours in the opposite direction.

(5) Rapid Pressure Cycling

(a) 50-hour steady state operation at 3/4 load and the pressure being cycled from 0 to 4000 psi and back at a rate of 4 cycle per hr., 25-hour steady state operation in one direction of rotation and 25-hour steady state operation in the opposite direction of rotation. Nominal voltage of 120 vdc. Water temperature at 40° F.

(b) 50-hour steady state operation at rated load under same conditions as (5)(a).

(6) 150-Hour Rapid Pressure Cycling—The drive system will be run at rated load for 75 hours in one direction of rotation and 75 hours in the opposite direction of rotation with the temperature of the water in the pressure tank maintained at 40° F and the pressure cycled from 0 to 4000 psig and back at the rate of 4 cycles per hr. The input voltage to the controller will be varied from 100 to 140 vdc.

c. Other Testing

(1) A 9000 psi test at 40° F will be conducted to obtain system speed-torque-efficiency characteristics at minimum and maximum input voltage.

(2) A 12000 psi test at 40° F will be conducted to obtain system speed-torque-efficiency characteristics at minimum and maximum input voltage.

(3) A sea-water contamination test will be conducted for the a-c systems. The motor's compensating fluid will be replaced by seawater and the system will be operated under full load for 100 hours at 4000 psi. At the end of this time it will be cleaned and flushed with fluid; then wear determination and corrosive effects on bearings and materials determined.

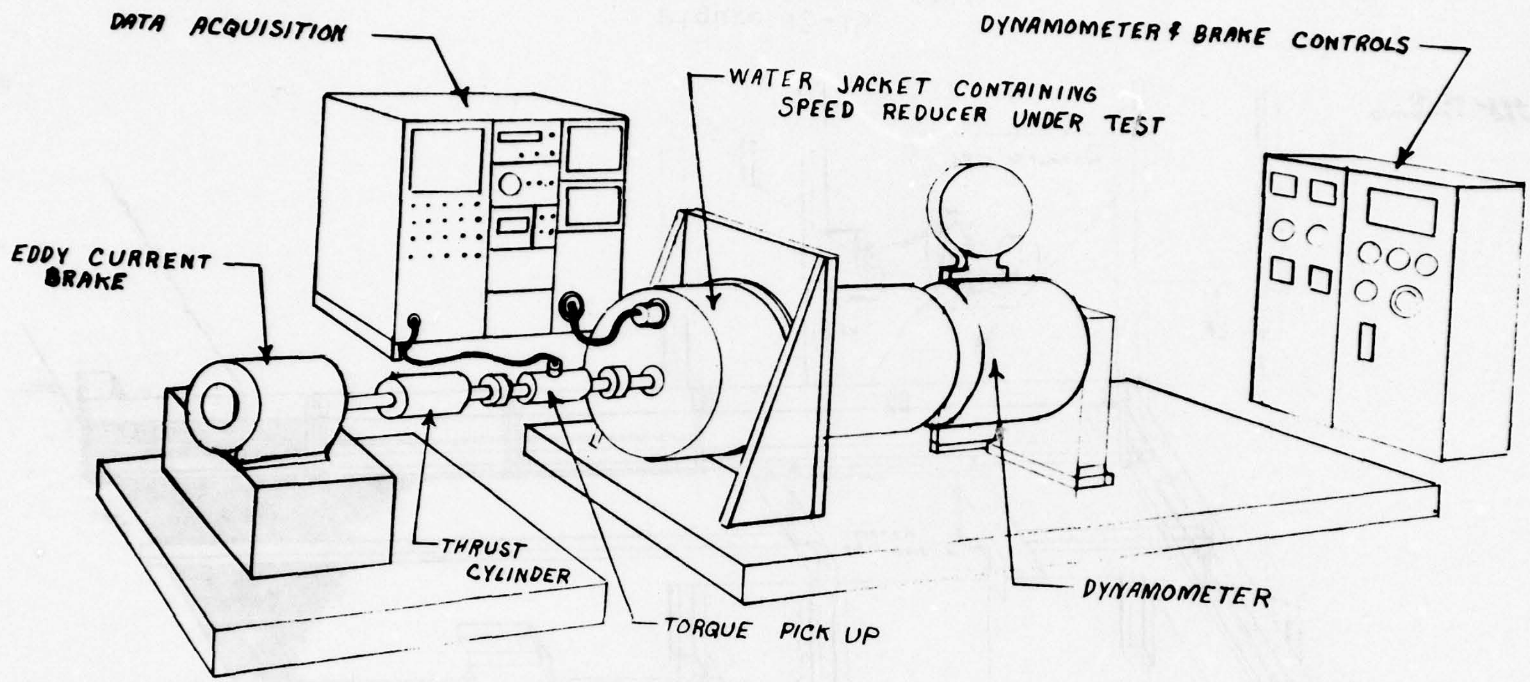


Figure I3-14
Component Beach Test Facility

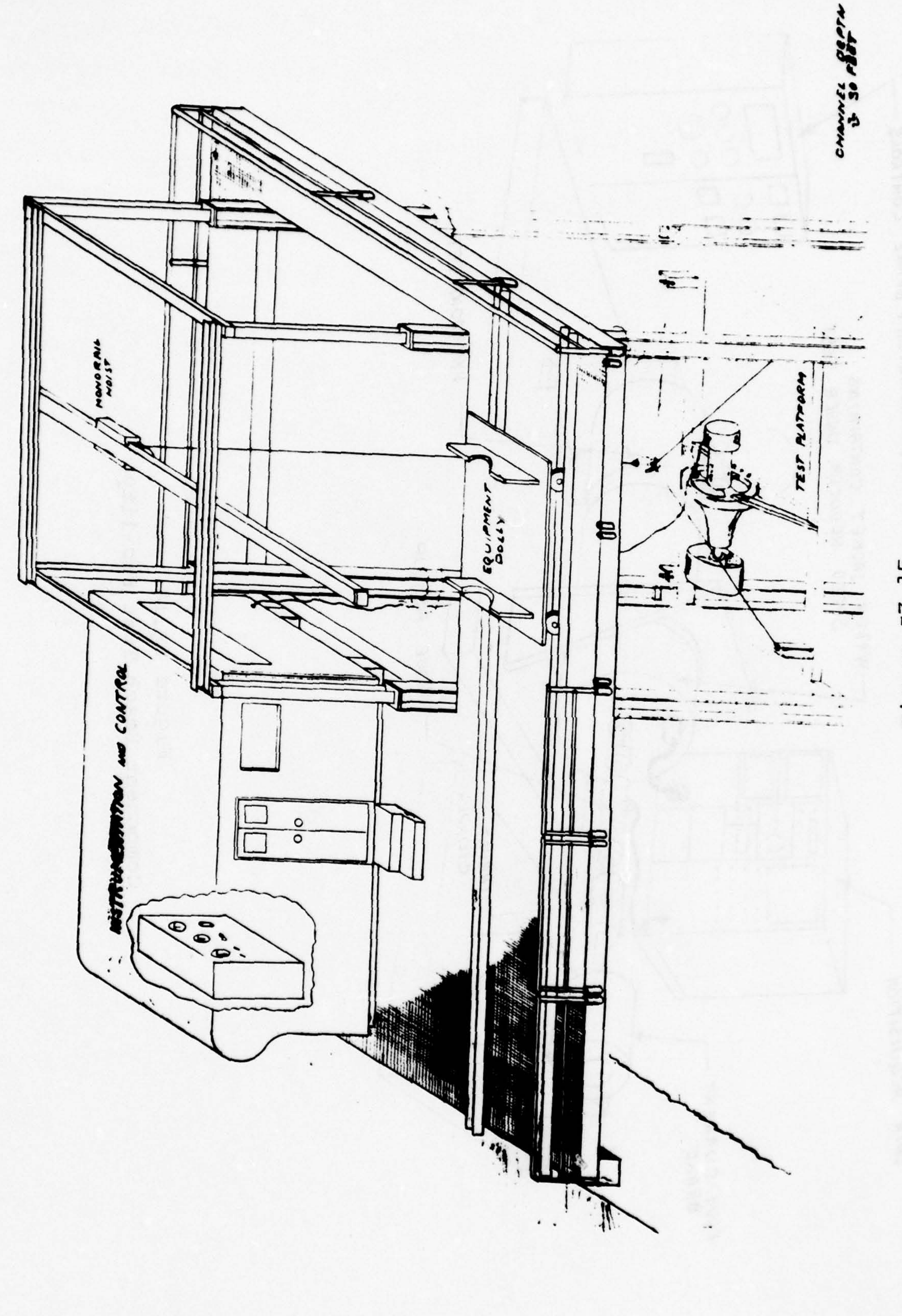


Figure 13-15
Shallow Water Test Facility

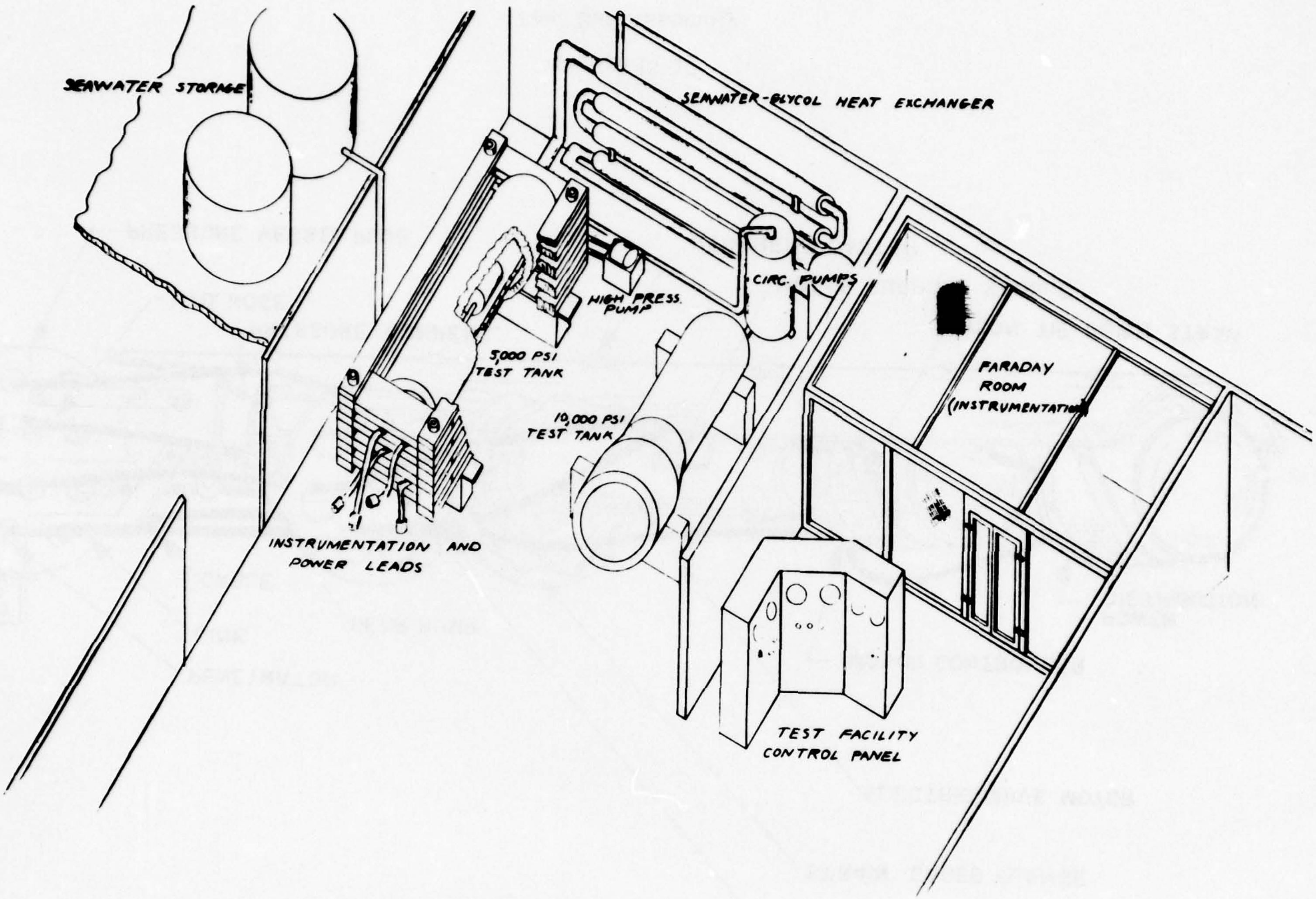


Figure I3-16
Pressure Test Facility

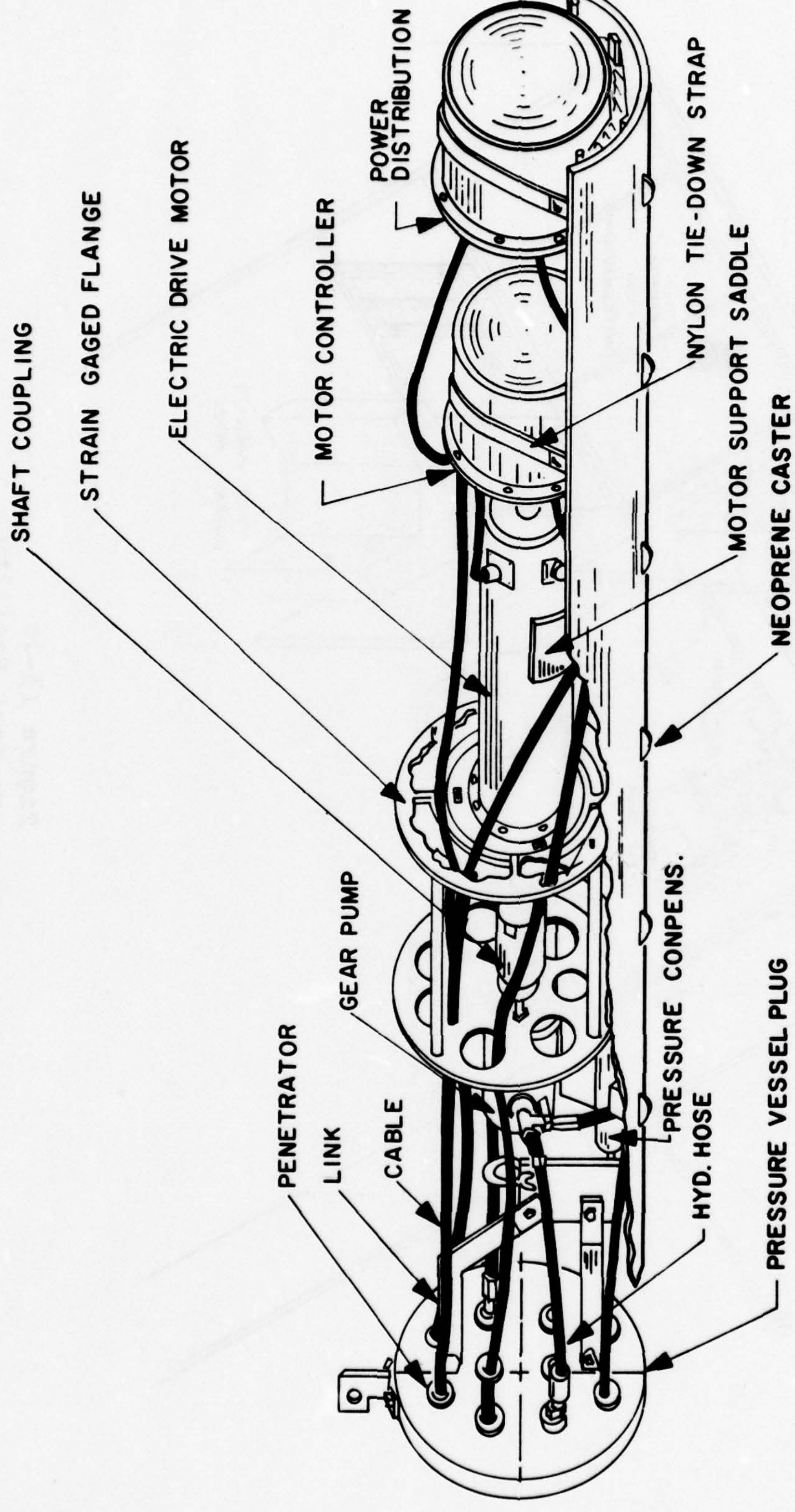


Figure I3-17
Test Bed Assembly

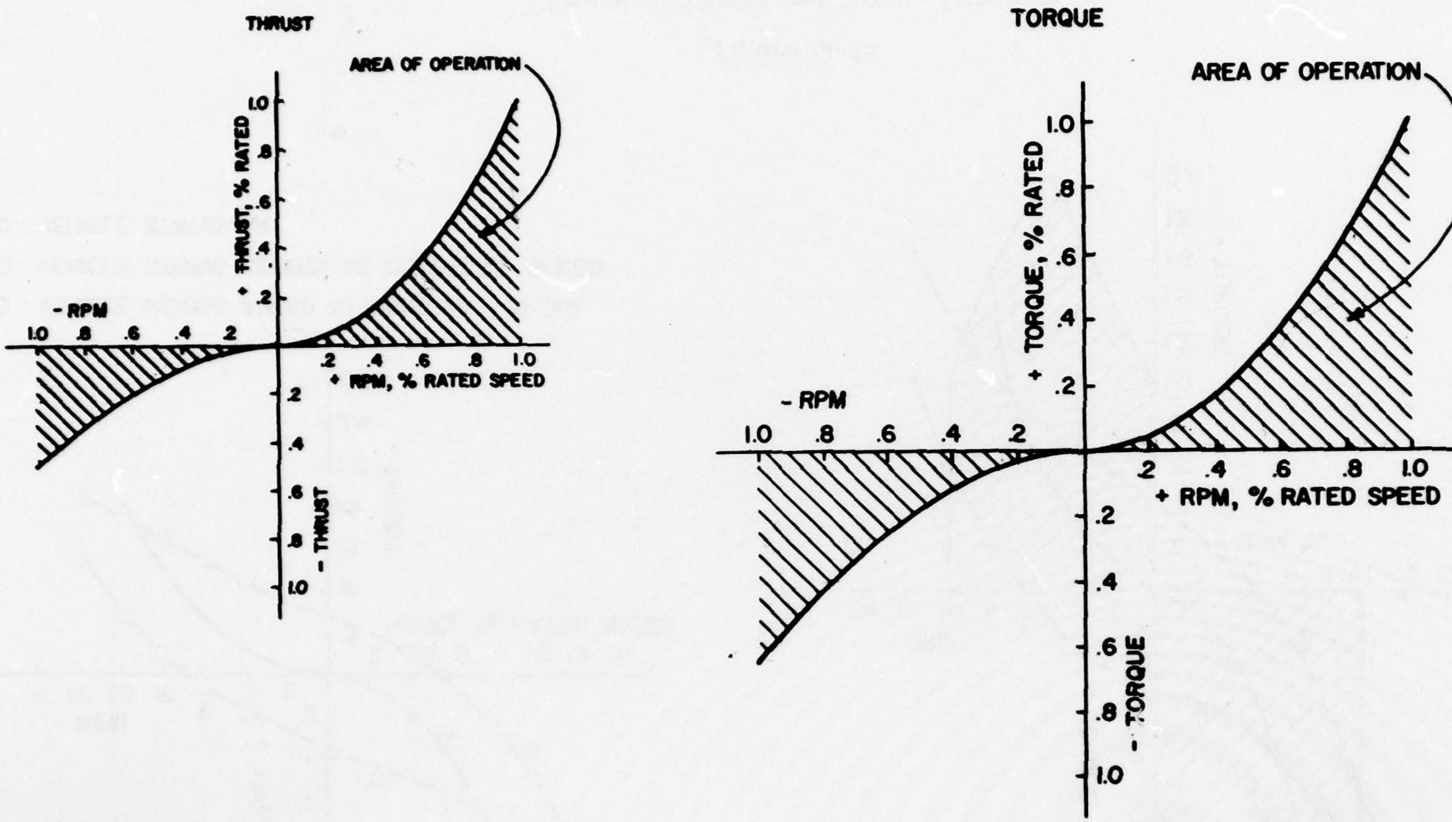


Figure I3-18

Steady State Thrust and Torque Loadings

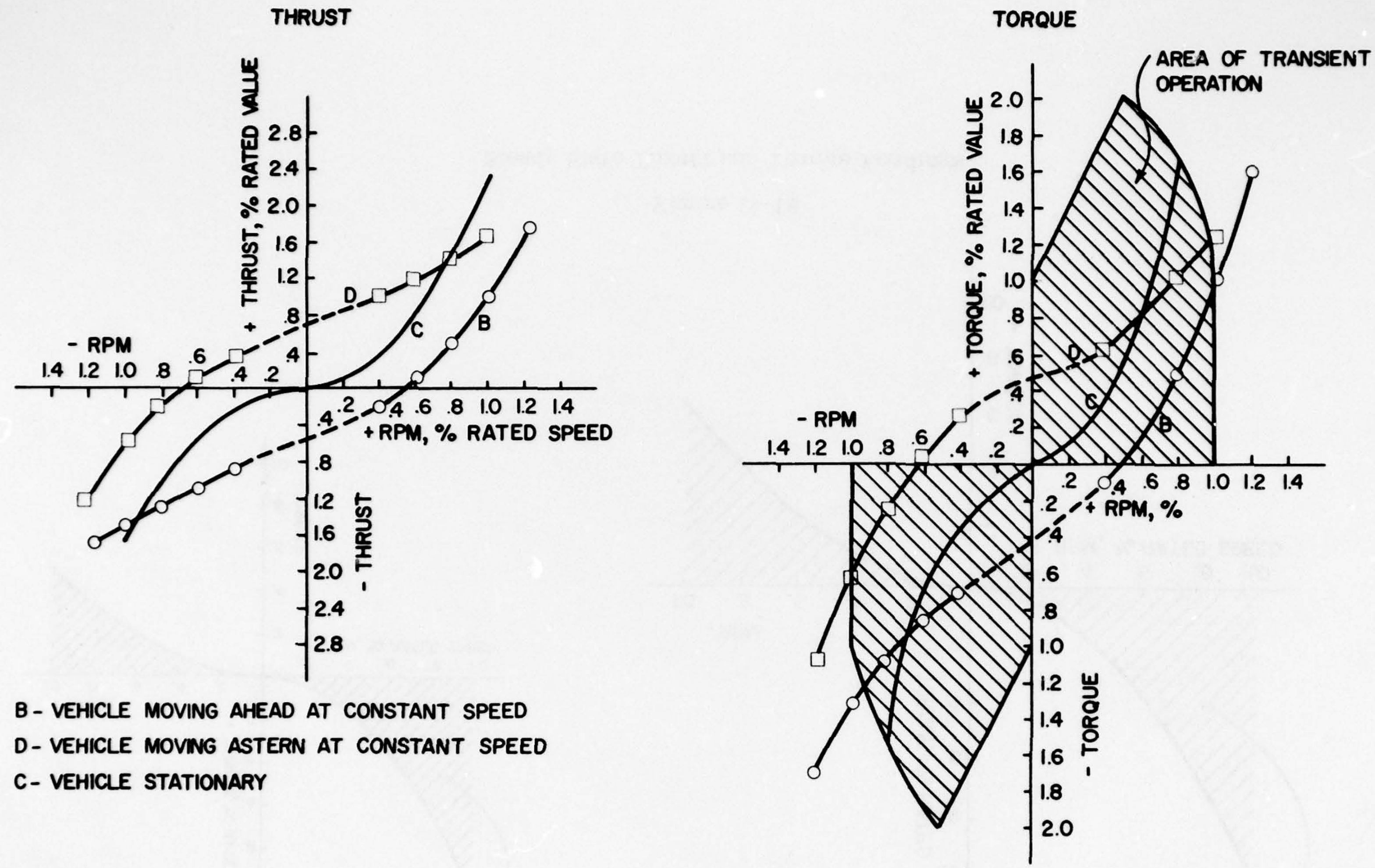


Figure I3-19

Transient Thrust and Torque Loadings

Enclosure (4)

MAY 1968 STATUS REPORT
DOT FLUIDS AND LUBRICANTS FOR POWER TRANSMISSION
AND PRESSURE COMPENSATION SYSTEMS ON DSV
TASK AREA S4728, TASK 12315
WITH ANNEX I-4

Introduction. This status report covers work accomplished from 1 December 1967 to 1 May 1968 on the program described in ANNADIV NSRDC Program Summary, Sub-project S4728, Task 12315, Problem 81 118, titled, "Fluids and Lubricants for Power Transmission and Pressure Compensation Systems on DSV (U)." This is the second status report since the start of work 1 September 1967.

Approach. A concurrent three-phase approach to the selection and development of fluids and lubricants for deep submergence vehicle (DSV) is still being followed.

In Phase I a survey of DSV systems and their requirements was made. A study of performance characteristics of potentially available fluids and lubricants was made so that the most satisfactory fluids could be selected.

Phase II consists of the development of improved fluids and lubricants.

Phase III involves a long range development. It has a goal of producing an ultimate fluid for all applications where power transmission or lubrication is involved.

Accomplishments.

- Milestone 1 - Complete survey of fluid and lubricant needs and performance of available fluids and lubricants on existing DSV, with recommendations of fluids for interim use in DSV systems describing limitations. The contacts made with engineers and scientists in Government and industry have continued and have been expanded to include Boeing Aircraft, North American Aviation, Midwest Research Institute, Southwest Research Institute, Sperry-Rand Corporation, and Woods Hole Oceanographic Institute (operation of "Alvin" vehicle). Participation in the DOD ad-hoc working group for development of a hydraulic fluids handbook and participation on the SAE Committee A6, Aerospace Fluid Power and Control Technologies, continued to provide valuable inputs to the program.

The initial results of the survey (see the first status report) indicated that DSV operating requirements are beyond the scope of the performance characteristics of any one of the currently available fluids. It appears that at the current state of the art of available fluids, each operating requirement

may have to be met by a different fluid. The survey also indicates that most programs are concerned with immersion fluids to provide protection for electric motors and electric and electronic equipment. Three of the laboratories contacted (Electric Boat, Lockheed, and Westinghouse) have programs on hydraulic systems for DSV and are attempting to use existing petroleum oil fluids in a system that is contained in a fluid-flooded casing with the fluid acting both as pressure-compensating fluid and hydraulic fluid. One laboratory, Electric Boat, is working on a pressure-compensating system for batteries and is having some favorable results with a proprietary petroleum oil similar to a transformer oil. No laboratory is working on the lubrication of the reduction gears, and only one laboratory (Electric Boat) recognizes that a problem exists in this area. Gear lubrication is one of the tasks on the contract for the tandem propeller development. There is some limited work on lubrication in sea-water-contaminated systems at one laboratory (Sperry-Rand).

As the results of the survey of the state of the art are further accumulated and evaluated, the direction of NSRDC laboratory investigation work will be established. At present the indications are that it should be on corrosion inhibition, lubrication, and power-transmission fluids, while maintaining contact with other laboratories for the other aspects of the program. If other phases of the fluid development begin to lag, either the emphasis of the NSRDC program may be shifted or NSRDC will recommend a contract effort to bring all phases into coordination.

The fluids selected as the reference fluids for this program are tabulated below and in detail in Table 1.

Code	Identification	Fluid Base	Proposed or Actual Use
L-582	MIL-H-5606B	Petroleum	Hydraulic fluid & motor immersion fluid
L-633	MIL-H-6083C	Petroleum	Motor immersion & hydraulic fluid
L-597	VV-I-530	Petroleum	Battery, pressure compensation, motor immersion, electrical system immersion
L-574	MIL-O-6081B Grade 1010	Petroleum	Motor immersion
L-632	MIL-L-17672B MS 2110TH	Petroleum	Hydraulic fluid, gear lubricant
L-587	MIL-S-21568A	Silicone	Motor immersion, electrical equipment
L-575	VV-D-001078	Silicone	Motor immersion, electrical equipment

These oils cover a wide range of materials and of performance properties. While no one of the seven fluids may be completely satisfactory, sufficient suitable properties are present so that a starting point for fluid development will be established by a study of these oils under system operating requirements. A 110-gallon lot of each fluid has been received and samples of each have been supplied to Navy and contractor laboratories so that all performance studies will be made on the same lot.

During the course of the survey of the state of the art, it was found that the laboratories and equipment manufacturers had made use of available fluids in order to operate equipment. Samples of these fluids were obtained and preliminary tests are being carried out to compare them with the reference fluids. Table 1 is a complete list of all fluids studied in the program.

Samples of the reference fluids, plus a distilled water sample, have been sent to SFRAN NAVSHIPYD for measurements of fluid compressibility. The equipment to make such measurements has been installed in the Materials Laboratory at SFRAN NAVSHIPYD. Some preliminary tests have been performed at pressures up to 20,000 psi. Annex I-4 is a copy of the status report of this project as of 1 March 1968. Due to delays in receipt of the fluid samples from the suppliers, it was not possible to make all samples available to SFRAN NAVSHIPYD in time to meet their 20 March 1968 date required for completion of work by 30 April 1968. The effect of the delay has not yet been established.

Samples of all seven fluids have been supplied to the Naval Applied Science Laboratory for the cable insulation program. The Electrical Laboratory at ANNADIV NSRDC has a complete set of samples of these fluids for their electrical property studies.

Corrosion tests at atmospheric pressure have been started on all seven oils, and studies of properties at high pressure will begin as soon as facilities are available.

- Milestone 2 - Complete preliminary study of the effect of high pressure on viscosity of fluids and lubricants for deep submergence applications. Contract effort. Four proposals were received in response to a request for measurement of the viscosity of the seven reference fluids at applied pressures of 0, 3,000, 5,000, 10,000, 15,000, and 20,000 psi and temperatures of 35°, 100°, and 150° F. After a careful evaluation of all proposals, which included consultation with National Bureau of Standards research laboratory personnel, a contract was let to the Esso Research and Engineering Corporation Laboratory at Linden, New Jersey. The project engineer at Esso Research and Engineering Corporation will be Dr. W. Phillipoff, who has had many years of experience in fluid rheology research and is a recognized authority on viscometric measuring techniques. The measuring technique to be used is based on the effect of viscosity of the

L-582 Identification Petroleum
MIL-H-17672B Fluid Base Hydraulic fluid & motor immersion

medium on the piezoelectric properties of a quartz crystal. The method yields a repeatability of better than 1%. Samples of all seven reference fluids have been sent to the contractor and the contract report should be received prior to 30 June 1968.

- Milestone 3 - Complete procurement of equipment and study effect of high pressure on viscosity of fluids and lubricants. A survey of the state of the art of viscosity pressure work is now complete. When the results of Milestone 2 are received and evaluated, a decision will be reached whether to develop an in-house capability or continue with contract efforts in this area.

- Milestone 4 - Complete procurement and construction of a hydraulic system test facility for evaluation of improved fluids and test with existing fluids to establish a base line for evaluation of improved fluids. The construction of all high pressure test facilities is now considered under this milestone. The high pressure test facilities being constructed for the program include five units capable of testing at 20,000 psi. These are:

a. One static test vessel for continuous pressure.

b. One stirred test vessel for continuous pressure.

c. &d. Two dynamic test vessels for pressure cycling.

e. One hydraulic circulating loop system.

Units a. and b. will operate at a continuous pressure for the duration of each individual test. Units c. and d. will operate on a set time cycle. Both latter units will operate independently but on the same time cycle. The first cycle tests will be done by pressurizing to 20,000 psig over a 15-minute period (linear increase) and then bleed down to atmospheric pressure over a 15-minute period. Unit e. is a 20,000 psig test facility which will cycle fluids at approximately 3 gpm.

The status is as follows:

a. All items are on order; most items have been received.

b. Unit a. has been assembled and tested at a temporary location. Tests have shown that the system is bubbletight at 20,000 psig. This unit will have to be reassembled in the permanent site when it becomes available. The system is now operable and a material compatibility test is being started.

c. The pressure cycling system has been tested on Unit a. The cycles are repeatable to less than ±1 minute.

d. Drawings for the test cells in the permanent location are complete and have been submitted to the Planning and Estimating Branch. Present shop loading schedules indicate that installation cannot be completed before the end of July 1968.

- Milestone 5 - Complete Technical Development Program for long range development of ultimate fluids in conjunction with NAVSEC (SEC 6101F) and Mare Island Division of San Francisco Bay Naval Shipyard. This milestone has been deleted since no fluid TDP is now planned. However, a draft of a proposed TDP 46-36X, "Deep Ocean Technology Project," prepared by the Naval Undersea Warfare Center, Pasadena, California, was reviewed and comments forwarded.

- Other Milestones in Progress - Complete investigation of material compatibilities of fluids in conjunction with Electrical Laboratory and Machinery Laboratory at ANNADIV NSRDC (Milestone 3, FY 1970). Compatibility studies will begin with an uncontaminated MIL-H-6083C fluid in a static vessel at 20,000 psig. The first measurements will be on seal materials, electrical materials, and coatings.

Table 1
Fluids for DOT Program Studies

Materials Lab'S
Identification'Specification Military Symbol'Trade Name or Batch or Lot No. E. F. Houghton & Co.
MIL-L-17672B*'MS-2110 TH Other Identification Batch PA-7456, WJB-8195'Humble Oil & Ref. Co. 'Composition of'
MIL H 81019B Qual Rept NAEL-AML-' Batch PA-7456, WJB-8195''''''Humble Oil & Ref. Co. '''''Composition of'
Materials Lab'SMIL-L-17672B*'Military Symbol'Qual Rept NAEL-AML-1111'Batch PA-7456, WJB-8195-11111'Humble Oil & Ref. Co. 11111'Composition of'

NSRDC Materials Lab Identification	Specification	Military Symbol or Grade	Trade Name or Other Identification	Batch or Lot No.	Supplier	Composition of Base Oil
L-582	MIL-H-5606B*	-	Qual Rept NAEL-AML-78368-66	Batch B-5560	Penn. Ref. Co.	Petroleum
L-633	MIL-H-6083C*	-	-	Batch 8822	Penn. Ref. Co.	Petroleum
L-597	VV-I-530a*	Class 1	Esso Univolt 33	Batch RL-11	Humble Oil & Ref. Co.	Petroleum
L-574	MIL-L-6081C*	MS-1010	-	Batch PA-7456, WJB-8195	Texaco, Inc.	Petroleum
L-632	MIL-L-17672B*	MS-2110 TH	Hydraulic Oil 681	Batch F-4769	E. F. Houghton & Co.	Petroleum
L-587	MIL-S-21568A*	1 Cs	DC 200-1.0	Lot AA 7078	Dow Corning	Silicone
L-575	VV-D-001078*	10 Cs	DC 200-1.0	Lot AA 6969	Dow Corning	Silicone
L-647	-	-	Submersible Fluid 2	-	Hoover Electric Co.	Petroleum
L-615	-	-	Primol 207	MR-A-RL-2941	Humble Oil & Ref. Co.	Petroleum
L-569	-	-	Tellus Oil 27	-	Shell Oil Co.	Petroleum
L-555	-	-	PR-1192	Batch F-4944	E. F. Houghton & Co.	Petroleum
L-547	MIL-H-6083B	Type 1	-	-	Royal Lubricants Co.	Petroleum
L-603	-	-	Tellus Oil 11	65201	Shell Oil Co.	Petroleum
L-504	-	-	Tellus Oil 15	65203	Shell Oil Co.	Petroleum
L-552	VV-D-001078	0.65 Cs	DC-200-.65	Lot AA 6642	Dow Corning	Silicone
L-559	MIL-S-21568A	1.0 Cs	DC-200-1.0	Lot 6860	Dow Corning	Silicone
L-556	MIL-S-21568A	1.5 Cs	DC-200-1.5	Lot AA 6851	Dow Corning	Silicone
L-665	VV-D-001078	2.0 Cs	DC-200-2.0	Lot AA 6850	Dow Corning	Silicone
L-666	MIL-S-21568A	3.0 Cs	DC-200-3.0	Lot AA 6698	Dow Corning	Silicone
L-667	MIL-S-21568A	5.0 Cs	DC-200-5.0	Lot 6849	Dow Corning	Silicone
L-143	VV-D-001078	50.0 Cs	DC-200-50	Lot AA 6194	Dow Corning	Silicone
L-585	VV-D-001078	0.65 Cs	SF-96-.65	Lot 9042	General Electric	Silicone
L-589	MIL-S-21568A	1.0 Cs	SF-96-1.0	Lot B 325	General Electric	Silicone
L-590	VV-D-001078	10.0 Cs	SF-96-10.0	Lot 2023	General Electric	Silicone
L-626	-	1 Cs	Y-6068/1	Lot AA 6515	Union Carbide	Silicone
L-625	-	10 Cs	Y-4816/10	Lot 181021767	Union Carbide	Silicone

*The reference fluids are designated with an asterisk. The remaining are fluids of interest and base fluids covering a broad range of fluid characteristics.

Table 1 (Cont)

NSRDC Materials Lab Identification	Specification	Military Symbol or Grade	Trade Name or Other Identification	Batch or Lot No.	Supplier	Composition of Base Oil
L-627	VV-D-001078	10 Cs	L-45/10	Lot 6000 13068	Union Carbide	Silicone
L-628	VV-D-001078	50 Cs	L-45/50	Lot 6000 3110767	Union Carbide	Silicone
L-610	-	1 Cs	SF-1143-1	DSRM-2377	General Electric	Silicone
L-630	-	-	Base oil used in MIL-H-5606B (Code A)	-	Penn. Refining Co.	Petroleum
L-631	-	-	Base oil used in MIL-H-6083C (Code B)	-	Penn. Refining Co.	Petroleum
L-617	-	-	Royal C-141	-	Royal Lubricants	Petroleum
L-573	-	-	NDH Fluid TD4-1	-	New Departure	Petroleum
L-644	MIL-L-7808F	MIL-L-7808F	-	-	Royal Lubricants	Synthetic diester
L-643	MIL-H-81019B	MIL-H-81019B	-	-	Royal Lubricants	Petroleum
L-645	-	-	Brayco Micronic 713	Batch B-7251	Bray Oil Co.	Petroleum
L-646	-	MIL-H-25598	Brayco Micronic 762	Batch B-8LM4	Bray Oil Co.	Petroleum
L-531	MIL-F-17111 (NORO) AM. 1	-	-	Batch 8271	Penn. Refining Co.	Petroleum
L-602	MIL-H-27601A (LSAP) AM. 1	-	-	Lot 12, Nov 1967	Humble Oil & Ref. Co.	Petroleum
	MIL-H-46004	-	-	-	Royal Lubricants	Petroleum

Annex I-4

Fluids and Lubricants Project, Deep Ocean Technology Program
(Sub-project S4728, Task 12315)
Status of Compressibility of Fluids Work for
San Francisco Bay Naval Shipyard letter
10350-130L2-21 dated 14 March 1968

C O P Y

SAN FRANCISCO BAY NAVAL SHIPYARD
Vallejo, California 94592

in reply refer to:
10350
130L2-21
March 14 1968

From: Commander, San Francisco Bay Naval Shipyard
To: Commander, Naval Ship Systems Command

Subj: Fluids and lubricants project, Deep Ocean Technology program (subproject S4728, Task 12587); status of compressibility of fluids work for

Ref: (a) NAVSHIPS ltr 10350 Ser 6101F-1117 of 14 Dec 1967

Encl: (1) Status report as of 1 Mar 1968

1. By reference (a), this Shipyard was assigned the subject investigation and funded $12, 000. 00, with the final report due by 30 April 1968. Enclosure (1) is a detailed status report as of 1 March 1968.

2. Test methods, facilities and procedures have been checked and one of several volumeters has been calibrated. Since funds limitations prevent checking fluids one by one, further testing is held in abeyance until all fluids are received. In the meantime, additional volumeters are being built and calibrated.

3. The completion date can be met if the remaining fluids are received prior to 20 March 1968.

O. L. MITCHELL
By direction

Copy to:
NAVSEC (6101F)
USNRDC Annapolis (Dr. R. McQuaid, M815)

C O P Y

COMPRESSIBILITY OF FLUIDS VERSUS PRESSURE AND TEMPERATURE

Status of Project - 1 March 1968

1. INTRODUCTION. The San Francisco Bay Naval Shipyard was assigned the task of determining the compressibility of seven compensating fluids and a distilled water control, at seven pressures (up to 20,000 psig) and at three temperatures (35°F, 100°F and 150°F). This is a detailed status report as of 1 March 1968, about two months after the start of the investigation.

2. DISCUSSION AND STATUS. This investigation required new techniques and equipment. The major effort has been to devise, proof test and calibrate recording volumeters (a more apt term than the previously used pycnometer or dilatometer) and to prepare the pressure test facility for these test conditions. The details are:

a. Test fluids. Distilled water will be obtained locally. Of seven test fluids to be provided by NSRDC Annapolis, only four have been received. Tracer action has been started from both ends to locate the missing three. Of those received, laboratory certification tests are complete. One oil (MIL-L-17672B) failed emulsification requirements. This has been discussed with NSRDC Annapolis, and work with this oil is in abeyance pending their decision. The other three available fluids will be tested on schedule.

b. Volumeter. Our equipment and methods previously used for compressibility work are not economical for a large number of test conditions. It is a single-shot volumeter requiring a complete pressure cycle for each datum point. A recording volumeter is required that can be recycled without opening the pressure system.

(1) Such a recording volumeter was designed, built, and tested. Our previous experience using a transfer liquid (mercury) to indicate compression was employed. This volumeter worked initially, but quickly developed problems. At this point, a parallel development was initiated. While the first design may now be ready for use, the parallel development appears to be more promising.

(2) A floating piston recording volumeter was developed. The piston seals but slides freely in a small cylinder that penetrates the wall of the volumeter. The only pressure differential is that required to move the piston. The face side of the piston is in contact with the test fluid. The back side is exposed to the pressurizing fluid. Once the cylinder ahead of the piston and the volumeter are filled with the test fluid, and sealed, the position of the piston is a function of compression of the test fluid. This

continuously is recorded, sensed by an electro-mechanical position transducer. The feasibility model is made of brass. It is crude but practical for the test conditions, as evidenced by the comparability of the curves for distilled water (Figure (1)). A more refined model of this floating piston volumeter (FPV-1) has been designed and additional volumeters are planned.

c. Submergence Test Facility (STF) Support. The high pressure test tank system of the STF has been set up and modified to support this investigation. It is working dependably to above 20,000 psig. The whole complex is set up in a large environmental test chamber in order to control temperature.

d. Test Results. To date no test results have been obtained that are usable for this investigation. Many tests have been made but they were involved with volumeter developments. In certifying the first floating piston volumeter (FPV-1), however, a test on water at 35-37°F, to above 20,000 psig, gave compressibility results that closely agree with Bridgman's data (Figure (1)).

(1) Valid testing could begin now, therefore, on one fluid at a time. This is uneconomical and not being considered. More than one fluid must be tested at once in order to complete the investigation with remaining funds. Further work is not planned, therefore, until the remaining fluids have been received and/or additional volumeters are made. The new volumeters will be the FPV-1A model. A rough cost optimization estimate is progressing to determine how many fluids should be tested simultaneously.

(2) We intend to present for each fluid a graph with data points and tabulation of compressibility versus temperature for a family of pressures. Two additional intermediate temperature runs will be made, however, in order to define the shape of the curves. This type graph is desirable because it is impractical for us to set the temperature due to adiabatic heat generation and limitations of the chamber. Cross-plotting will be simple and valid. This was agreed to in oral discussions between Mr. O. L. Mitchell (SFBNS Code 130L2), Dr. R. McQuaid (NSRDC Annapolis Code M815) and Mr. A. Barusch (NAVSEC Code 6101F) during the week of 19 February 1968.

e. Viscosity. We agreed orally to attempt to obtain viscosity data as a companion determination during these tests. The additional costs to do this could have been incidental to compressibility determinations if developmental work had been done on our planned recording viscometer. As it is, the cost and time expended to develop the volumeter now preclude also including viscosity data. We will try, however, to obtain some viscosity results.

3. <u>PROJECTION</u>. We plan to complete the subject work, with the remaining funds, by 30 April, provided the missing fluids are received by 20 March. Change in this situation will be reported promptly.

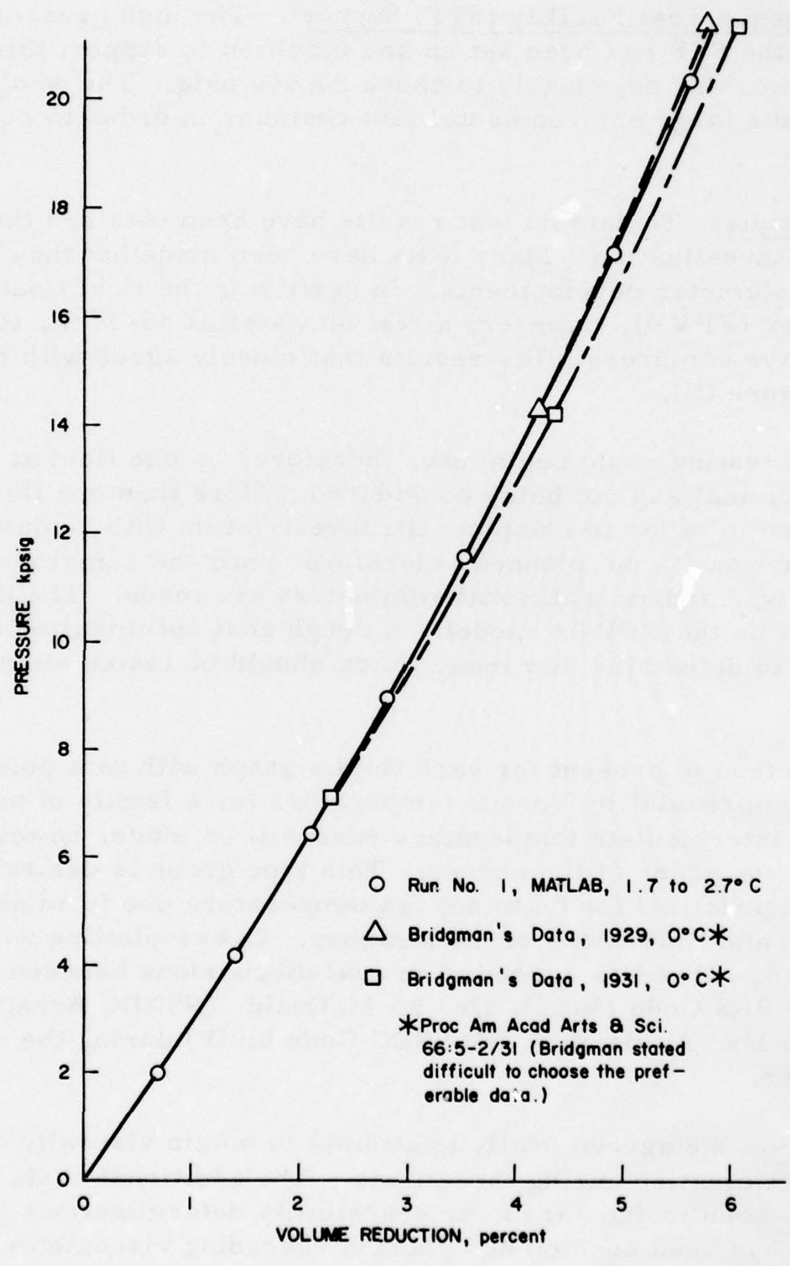


Figure 1 - Compressibility of Water Using Volumeter 1

Enclosure (5)

MAY 1968 STATUS REPORT
DOT DSV ELECTRICAL PROTECTIVE AND SWITCHING
DEVICES IN FLUID PRESSURE AMBIENT
TASK AREA S4728, TASK 12319
DOT DSV ELECTRICAL COMPONENTS AND MATERIALS
IN FLUID PRESSURE AMBIENT
TASK AREA S4728, TASK 12317
WITH ANNEX I-5

INTRODUCTION

This status report presents the data which will form the basis of an organized investigation of the means to make electrical equipment operate in fluids at ambient deep ocean pressures. The report is divided into two portions: (1) that portion associated with the electrical dielectric characteristics of insulating fluids and materials as affected by contaminants, and (2) the portion associated with the reliable operation of electrical protective and switching devices that are immersed in similar fluids. The schedule for the activities of each task is presented in Annex I-5.

PART ONE

Objective. Part (1), Task 12317, To develop electrical insulation systems that will have an operating life of at least 5 years in a fluid environment at cycling pressures up to 13,300 psi. These systems must protect the electrical conductors of motors, generators, solenoid coils, transformers, and solid state and other devices from the high pressure of deep ocean sea water.

Background. Electrical insulation systems technology for exposure to deep ocean environments has been found to be primitive. Existing systems consist of modified commercial devices and methods. Operational experience with the present systems shows major technical difficulties and missions aborted due to failure of various system components. This task was started to make an orderly investigation of the problems involved and to develop insulation systems that will perform satisfactorily in the deep ocean environment.

Since so little was known about the compatibility of insulating materials and fluids, the initial effort was to document the behavior of 11 fluids most likely to be encountered (by past

usage for this purpose) with several well-known insulating and encapsulation materials. This step was required to establish a firm basis for future, more precisely definable procedures.

APPROACH

a. Conduct dielectric studies on each of the following fluids and on each of these fluids including the indicated percentage of sea-water and carbon dust contaminants.

	Initial Fluids	NSRDC MATLAB Identification	Seawater %	Carbon Dust grams per 250 ml of fluid
*(A)	MIL-H-5606B	L-582	0.25	0.013
(B)	MIL-H-6083B		0.5	0.026
*(C)	DC-200 1 c.s.	L-587	0.75	0.039
(D)	DC-200 50 c.s.		1.0	0.052
(E)	Transformer Oil		2.0	0.065
*(F)	M.S. 1010	L-574	2.5	
(G)	Primol 207		5.0	
(H)	GE SF 96-1 1 c.s.		7.5	
*(I)	MS 2110 TH	L-632	10.0	
*(J)	VVI-530	L-597		
*(K)	DC-200-10	L-575		

* Reference fluids supplied by the Fluids Project, Task 12315.

b. Study the effect of pressure cycling on the dielectric strength of fluid with contaminants as above.

c. Study dielectric breakdown of magnet wires in air, fluids, fluids with various levels of contamination, and after subjection to pressure cycling.

d. Study compatibility of various insulating materials in fluids under long term submergence (at least 1 year).

e. Study typical insulation systems in specific fluids to determine compatibility at room temperature.

f. Study insulation characteristics of fluids as a function of temperature at various pressures.

g. Study life and compatibility of insulation systems when subjected to accelerated aging conditions to establish thermal rating at pressure of 13,300 psi.

h. Develop materials qualification procedure.

i. Prepare applications guide for materials and insulation systems that will meet immediate performance criteria.

j. Develop new and improved insulation systems that will provide maintenance free, longlife, highly reliable electrical equipment performance.

RESULTS

a. Approach Item - a.- The electrical characteristics of the various insulating fluids were obtained by using the standard test cup specified in ASTM standard D877-49 with standard electrodes spaced at 0.100 inch. The data are shown in Table 1.

The dielectric breakdown of the various insulating fluids with various degrees of simulated sea-water contamination are given in Table 2. The breakdown information was also obtained with a gap setting of 0.100 inch. Each entry is the average of five individual determinations.

b. Approach Item - b.- Samples of the same fluids and contaminants were subjected to pressure cycling from atmospheric pressure to 6000 psi. Constant 6000 psi pressure was kept on the fluids over weekends and during the 16-hour nonworking part of each day. During the working day, continuous cycling occurred. The breakdown voltages and number of pressure cycles that each fluid was exposed to (until failure occurred) are given in Table 3.

In Tables 2 and 3, most of the fluids reached a condition where the electrical characteristics were such that with the standard test device the leakage current at minimum voltage on

the test electrodes exceeded 0.100 ampere and tripped the failure indicating circuit breaker. Under these conditions, no dielectric strength determination could be made.

The most significant factor in this portion of the investigation is that in some cases pressure cycling significantly reduces the dielectric strength of insulating fluids.

c. Approach Item - c.- A study was made of the performance of magnet wire insulation when immersed in these various fluids. Studies were made of the breakdown of the magnet wire insulation in air as a reference comparison, and then in the different fluids with simulated seawaters and carbon dust as contaminants to determine the effect of the fluid and contaminants on expected performance of the system.

The magnet wire insulations used in this country are, except in rare special purpose systems, limited to polyvinylformal (formvar), polyimide (ML), and cross linked polyester with linear polyester overcoat (polythermaleze). The polythermaleze magnet wire film is hydralized by water and cannot be used in its presence. Therefore, only twist samples of formvar and ML magnet wire were constructed in conformance to test standard ASTM D 2307-64T.

These samples were immersed in the various fluids and with the various amounts of contaminants. Dielectric breakdown tests were performed on at least ten samples under each condition. The results of these studies are given as average breakdown voltages in Tables 4 through 8. These data are plotted on graphs of contaminants versus voltage breakdown (Figures 1 through 8).

When the samples were pressure cycled (see Figures 4 and 8), a significant decrease in breakdown voltage was found with increased amounts of contamination continuing in each case to the point of failure. When no pressure cycling was used, the dielectric breakdown of the twists in fluids was fairly constant until catastrophic failures were encountered. From these points of failure on, no significant voltage could be applied to the twist test sample because globules of water shorted the sample or the leakage current was sufficient to prevent further testing.

d. Approach Item - d.- Samples of typical insulating materials, used in the electrical equipment proposed for deep ocean vehicles, were thus far exposed to four of the insulating fluids to determine their compatibility. To date the samples

have been kept in closed containers for five months at atmospheric pressure and at a standard temperature of 70° F and 50% relative humidity. Periodic inspections were made during the period of the test.

The laminate samples were coupons cut from samples of laminated sheet materials. These were checked for visual change and measured to detect dimensional change. Magnet wire samples No. 20 were standard twist samples made in accordance with ASTM D 2307-64T and subjected to the standard 1000-volt screening test. Lead wire samples were short lengths of the wires selected and were inspected for dimensional change or significant change in physical properties. The epoxy material samples were coupons about 1/8 inch thick. The results of this investigation are given in Table 9.

e. Approach Item - e.- Ten motorette units were fabricated in accordance with AIEE test method 510 using the insulating system of the Lear-Seigler motor, which is undergoing laboratory investigation at this activity. One purpose of this investigation was to determine if the electrical characteristics of a typical insulation system such as the one used here is affected by the properties of the insulating fluid in which it operates. Four of the ten motorettes exposed to the fluids were immersed in hydraulic oil meeting the requirements of Military Specification MIL-H-6083B. This fluid was being considered for use in the Lear-Seigler motor. The results of these studies showed severe degradation of the insulation system within 30 minutes when immersed in the poor dielectric fluid. The component materials of this insulation system and the results of the studies are given in Tables 10 and 11. This gives an indication of the extent to which the fluid's poor electrical properties degraded the electrical properties of the original insulation system by penetrating the normal voids found in most varnished systems.

Also included in Table 11 are results of immersing this same insulation system in two better grade fluids. The results show no appreciable effect after 3 or 4 months.

A study of effects of water absorption on dimensional stability of typical motor encapsulating materials was made at atmospheric pressure in conjunction with work done to develop a submersible motor on Task 4829. The results of these studies are given in the Marine Engineering Laboratory Report 421/65 of March 1966.

Approach Items f. and g.- Little has been done on these items to date as the autoclaves have not been delivered.

Approach Items h., i., and j.- All the preceding efforts are the basis for the attainment of these three goals. The partial results to date have been discussed under Items a. through g.

CONCLUSIONS

a. There are materials that are compatible with specific fluids and can be used in electrical equipment which operates in that fluid. However, many materials are not compatible with certain fluids and additional information is required to ensure proper fluid-insulating material compatibility.

b. Conventional insulating systems are severely degraded when exposed to fluids with poor electrical properties, because of the numerous voids present in most currently used varnished systems.

c. Simulated seawater in dielectric fluids severely degrades the capability of insulation materials to protect electrical circuits.

d. Pressure cycling significantly decreases the dielectric strength of the insulation fluids that have been studied.

PART TWO

Objective. Part 2, Task 12319, to develop circuit interruption devices and circuit protection devices that will operate reliably in a high pressure and cycling pressure fluid environment. The devices are to have a life of at least 10,000 circuit interruptions. Calibration and performance must not be affected by temperature changes between 0° and 100° C nor by pressure changes between atmospheric and 13,300 psi.

Background. The reliable performance of electric power systems is dependent on the performance of the switching and protective devices. These devices are a major problem when they are immersed in insulating fluids and subjected to ambient pressures encountered by deep submersible vehicles. The pressure environment adversely affects the calibration of protective devices, and affects the capability of insulating circuit interruption devices to more effectively extinguish arcs. Development of solid state circuit interruption and sensing devices is one approach to the solution of these problems. Development of

reliable mechanical circuit interruption devices and the combination of solid state and mechanical circuit interruption devices offer some promise of achieving practical solutions.

A survey was made to enumerate existing switching and protective components that are being used under these unusual environmental conditions. Examination of these items in detail was expected to provide a kind of state-of-the-art basis from which to begin. The listing in Table 12 presents the components in actual use today, although no rationale is apparent as to why the items were ever selected. Furthermore, many of these items have already failed to perform to a minimum of adequacy.

APPROACH

a. Survey experience on circuit protection and interruption devices - a state-of-the-art review.

b. Determine the electrical properties of fluids and fluids containing contaminants as they are affected by electrical arcing.

c. Investigate current interruption phenomena in high pressure fluid environments - using both mechanical and solid state devices.

d. Establish qualification techniques and procedures.

e. Develop improved devices and methods including more reliable ratings of contacts in fluids and more precise methods of calibration.

f. Prepare application guides and specifications.

g. Develop and build a wet winding 7 1/2-hp, 580 rpm, 30-Hz, a-c motor for the submersible electric drive system - using the encapsulation and insulation techniques developed at ANNADIV NSRDC.

RESULTS

a. Approach Item - a.- The survey of existing switching and circuit interruption devices yielded those items listed in Table 12. However, the experience on all of these items has been generally poor and by past agreement those items used on the Trieste were eliminated because they had been designed for air operation and merely flooded with a silicone fluid of 1-centistoke

viscosity. Consequently, the intended purpose of using these items as a basis from which to proceed proved ineffective.

It became necessary to approach the problems from a more basis position. The simplest answer would be to find an insulating fluid in which arcing could take place for a sufficient length of time and/or the required number of operations under all of the anticipated environmental conditions. Accordingly, a series of investigations have been established and will be discussed in the following sections.

b. Approach Item - b.- The fluids listed under Part One, Approach, were placed between fixed disk electrodes and subjected to a series of repeated high voltage, 60-Hz arcings. The voltage was steadily increased each time until breakdown occurred. The procedure was repeated up to 1000 times. Observations were made of physical and chemical changes to determine if any differences in behavior existed among the various fluids. To date the following observations have been noted:

(1) Breakdown products - Arcing is accomplished by the formation of two general types of decomposition products:

(a) Solid breakdown products - These are finely divided materials black in color in the hydrocarbon (petroleum) oils, and grey in the silicone oils. The solid products have been separated from each test fluid by centrifuging. The volumes obtained are entered in Table 13. Identification of the products is in process, starting with Primol 207.

The silicone fluids showed a pronounced tendency to form conductive bridges of solid decomposition products between the electrodes, the tendency increasing markedly when higher viscosity fluids were used.

(b) Gaseous breakdown products - Bubble formation is observed in the discharge area. The gas is expected to be largely hydrogen but a determination of the smaller traces may give valuable data.

(2) Changes in the fluids:

(a) Electiecal properties - The insulating properties of each fluid were evaluated by measuring insulation resistance (IR), capacitance (C), dissipation factor (DF), and breakdown voltage. These data are presented in Table 13.

(b) Chemical composition - Thus far the chemical changes have been evaluated only by noting changes in physical appearance and by infrared absorption spectrograms. The hydrocarbon oils darken in color, while the silicones remain clear. So far, no changes have been detected in the infrared curves on any fluid tested.

(3) Several tentative conclusions can be drawn from the data recorded and analyzed thus far:

(a) The silicone fluids show a pronounced tendency toward dielectric breakdown and bridging of electrodes - as viscosity increases in the region of 10 to 50 centistokes.

(b) The hydrocarbon fluids appear relatively stable in their dielectric properties with two important exceptions:

- The marked decline in the breakdown voltage of the MIL-H-6083C is felt to be related to the presence of the corrosion inhibitor (not present in the MIL-H-5606B fluid). This probably also accounts for the lower insulation resistance.

- A decline in breakdown voltage of the Primol 207 is felt to be due to its higher viscosity. The results when obtained on MS-2110 TH should be interesting.

The test series needs to be completed. Breakdown products and gaseous products need to be analyzed and relationships established between product amounts and the energy and frequency of arcing. The results obtained may point the way to other fluids which may provide the required protection.

c. Approach Item - c.- The basic information being gathered in the above section will be augmented by additional data obtained from the actual operation of current-carrying contacts performing normal make-and-break operations in these same fluids. Operations at selected temperatures and incremental steps of pressure from 1000 to 13,300 psi will be examined.

Solid state circuits using silicon controlled rectifiers (SCR's) will be studied to establish their performance capabilities in fluids at pressure. Hybrid arrangements will be studied to determine whether simple arc suppression will be of value or perhaps techniques can be used to reduce heavy load currents by SCR's and then utilize mechanical circuit interruption

at the reduced current levels, to open the circuits completely. In fact, the effects of power level need to be established. Other techniques such as fluid jets and magnetic methods to reduce arcing and to prolong contact and fluid life will be considered. Contact materials in conjunction with various insulating fluids under arcing conditions also need to be evaluated.

Once the Trieste components had been eliminated for consideration from the items in Table 12, the Hartman relay was earmarked as the test specimen since it was the least expensive unit of those remaining, and a considerable number would be utilized in the contact arcing tests.

An experiment was set up to operate a group of these identical standard commercial relays in the various fluids until failure of the relay's nickel-plated brass contacts. The contact loads were originally set at 10 amperes from a 90 vdc source. To eliminate any effect from the materials on the relays' coils, they were coated with solvent-dispersing silicone rubber. This material was found to have no known effect on the various fluids being used, hence its selection.

Initially, a base line experiment was performed at atmospheric pressure and temperature with the single 10-ampere load current for later comparison with behavior at pressure. The data have presented some effects of arcing on the contact surfaces and changes to the fluids. Eventually some data are expected to indicate correlation between fluid properties and relay contact life. The same solid and gaseous breakdown products and contact bridging effects were observed as in the earlier tests on fluids. The same insulation resistance, capacitance of the fluids, dissipation factors, and breakdown voltage determinations were made. These data are presented in Table 14.

In addition, oscilloscope traces of both the make and break portions of the relay operations were photographed. The arc durations and energies are also recorded (Table 14). The faint arc observed on "contact make" is due to "contact bounce" and its energy is negligible in comparison to that of the "break" arc.

Six of the nine fluids have been subjected to 10,000 relay operations (both make and break) at the 10-ampere contact current load. The relay in the MS 1010 oil failed at that point, the others are still functioning satisfactorily. The failure was due to the transfer of metal from one contact to the other and,

consequently, resulted in poor contact mating. There is no way to correlate this event with fluid properties at this time.

Contact resistance was also measured by recording the voltage drop across the contacts with the 10-ampere load current flowing through them.

Finely divided metal particles and other light colored material possibly metal compounds, were observed in the test liquids. as well as the same black and grey products found earlier.

The following observations can be made at this point in the studies: The effect of arcing on the dielectric properties is similar to that in the earlier series - only more severe with all fluids except MIL -H-6003C. Its relative stability to breakdown voltage in these tests, as opposed to the former poor results, is not presently explainable.

The remaining steps in the experiment need to be completed. Selective tests must then be performed at different loads, temperatures, and pressures. Breakdown products must be determined. Other contact materials in combination with good insulating fluids must be considered. A further examination of the relationship between dielectric breakdown and viscosity of the insulating fluid is anticipated. The effects of pressure on the solid state circuits will be determined and the other methods of circuit interruption will be given additional emphasis.

d. <u>Approach Items - d., e., and f.</u>- These items listed as goals are in essence the output of Items a., b., and c. There is nothing specific to report in the way of tangible output at this time.

e. <u>Approach Item - g.</u>- The design has been firmed up for the 7 1/2-hp, a-c submersible motor, and parts have been ordered. When this motor is completed, it will be included in the upcoming tests of the submersible drives. The unit is being supplied largely as a state-of-the-art sample of insulation techniques rather than optimum motor design. This was a forced situation as both funds and time limitations did not permit purchase of optimum stator laminations, in size or quality of iron.

REMARKS

Very little basic knowledge is available on the performance of mechanical circuit interrupting devices in gaseous or fluid environments. Far too often "cut and try" methods are used to obtain a just usable device with a far lower life and reliability than is reasonably acceptable. It is the purpose of this task to learn enough basics to enable the deep submergence vehicles of the future to utilize circuit breaking devices of predictable reliability, whether they be of conventional design or of some hybrid solid state mechanical arrangement.

Table 1

Electrical Characteristics of Insulating Fluids
in Standard Test Cup - ASTM D877-49
Gap 0.100 inch

Oil	DF(%)	CAP(mu)	IR(100 Volts) (Megohms)
Cup with no fluid	1.87 DIR 1.12 REV	.285 x .0001 DIR .29 x .0001 REV	$\infty \times 10^6$
MIL-H-6083B	54.2 DIR 55.0 REV	.42 x .0001 DIR .41 x .0001 REV	1.75×10^2
2110 TH	2.45 DIR 1.1 REV	.33 x .0001 DIR .32 x .0001 REV	10.4×10^4
DC-200-1	2.45 DIR <.5 REV	.33 x .0001 DIR .32 x .0001 REV	2.87×10^5
SF-96-1	2.4 DIR <.5 REV	.23 x .0001 DIR .31 x .0001 REV	3.70×10^4
MS 1010	1.63 DIR <.5 REV	.34 x .0001 DIR .32 x .0001 REV	1.98×10^5
Primol 207	2.0 DIR <.5 REV	.32 x .0001 DIR .32 x .0001 REV	$\infty \times 10^6$
Sunold Transformer Oil	1.9 DIR .95 REV	.32 x .0001 DIR .32 x .0001 REV	7.5×10^5
MIL-H-5606-B	1.5 DIR 0.0 REV	.32 x .0001 DIR .31 x .0001 REV	9.1×10^4

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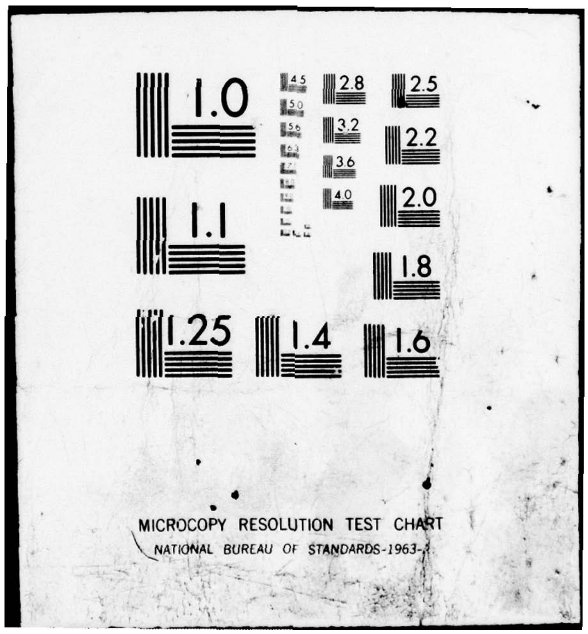
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
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3.6
4.0
4.5
5.0
5.6
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Table 2

Dielectric Breakdown of Fluid + % of Simulated Sea Water
in Standard Test Cup With Gap of 0.100 Inch (Thoroughly Mixed, No Pressure Cycling)

Fluid Key	Pure Fluid No Contaminants Average of 5	.25% S. S. W.	.5% S. S. W.	1% S. S. W.	2% S. S. W.	2.5% S. S. W.	5% S. S. W.	7.5% S. S. W.	10% S. S. W.
A	33700		NO READINGS Leakage Current Too Great						
B	34700	15860.3	8807.6	No Meaningful Readings Leakage Current Too Great					
C	31400	22800	14740	11400	8400	8349.9	7546.7	5865.5	5529.2
D	34700	6900	No Readings Leakage Current Too Great						
E	34100	8400	8100	8300	8500	8400	1774.6	765.6	709.8
F	26800	8420	3779.4	4203	3661.2	2802	3736	2598.3	2424.4
G	35000+	35000	Leakage Current Too Great No Meaningful Readings						
H	28030	25200	23200	8574	7509	4249	4062	3642	4436
I	32000	6257.8	7005	3082.2	934	1139.4	747.2	784.5	653.8

Table 3

Dielectric Breakdown of Fluid + % of Simulated Sea Water
That Has Been Pressure Cycled in Standard Test Cup With Gap of 0.100 Inch

Fluid Key	Pressure Cycled Fluid	P. Cyc. .25%	P. Cyc. .5%	P. Cyc. 1%	P. Cyc. 2%	P. Cyc. 2.5%	P. Cyc. 5%	P. Cyc. 7.5%	P. Cyc. 10%
A	35000 487 Cy	13081 845 Cy	7247.4 408 Cy	6855.4 (F) 587 Cy	*				
B	35000 487 Cy	16900 584 Cy	18400 546 Cy	6425.6 570 Cy	* 572 Cy				
C	28900 240 Cy	30600 584 Cy	23600 546 Cy	27200 587 Cy	16600 631 Cy	*			
D	16000 845 Cy	Less Than 5000V 329 Cy	* 467 Cy						
E	30800 324 Cy	18500 329 Cy	* 467 Cy						
F	23200 735 Cy	21136 640 Cy	2909.4 666 Cy	*					
G	23500 470 Cy	22800 588 Cy	12057.8 666 Cy	13700 570 Cy	*				
H	23100 640 Cy	29700 408 Cy	21681.8 823 Cy	3035.2 572 Cy	1336.8 631 Cy	*			
I	21100 470 Cy	6595.2 588 Cy	* 823 Cy						

*Leakage current too great- No meaningful readings obtained.

Table 4

Dielectric Breakdown Strength of Magnet Wire Twists in Air,
Oil, and in Oil Plus a Percentage
(As Indicated) of Simulated Sea Water

		0%	.25%	.5	1%	2%	2.5%	5%	7.5%	10%
Air	Formvar	11282.5								
	ML	10479.1	← Not Applicable →							
Air	Formvar	9470.3								
	ML	11637.3	← Not Applicable →							
A	Formvar	9942.0	12828	13552.0	12818.8					
	ML	8839.9	12067	14187.1	14738.2	← Note 5 →				
B	Formvar	14672.6	13159.0	12751.4						
	ML	12711.4	15616.3	14626.1	← Note 4 →					
C	Formvar	10974.2	10558.5							
	ML	8606.2	8942.7	← Note 2 →						
D	Formvar	12561.8	12295.5	11445.8	11711.9	9918.7	11179.7	11455.2	9951.3	
	ML	10007.4	9372.3	13066.4	13337.0	12157.2	12655.4	12667.6	10769.0	Note 6
E	Formvar	9722.6	12603.8	11973.5	11931.4	11100.1				
	ML	8634.4	12375.0	11903.4	12057.6	12160.3	← Note 7 →			
F	Formvar	10362.3	13169.2	12393.8	12608.6	11828.7				
	ML	8900.7	12581.2	14093.7	14233.6	14425.3	← Note 1 →			
G	Formvar	10633.9								
	ML	9465.7	← Note 3 →							
H	Formvar	11711.9	10828.4	10955.3	11146.9	11188.7	10787.2			
	ML	8685.7	9031.3	9353.5	8979.9	8746.3	9161.4	← Note 8 →		
I	Formvar	10040.2	11814.7	12678.7	13000.6	12823.5	11989.7			
	ML	9549.7	12076.1	11991.9	13024.3	11757.1	11796.1	← Note 9 →		

Notes to Table 4

Note 1: With 2.5% SSW in this oil the path is from electrode to electrode at approximately 5 KV.
With 5% SSW in this oil the path is from electrode to electrode with application of voltage.

Note 2: Water will not mix with oil and settles to bottom of test vessel in one or two large globules; the voltage starting at this to concentration jumps from the electrode to the water globule and trips breaker, making a dielectric breakdown of twist impossible.

Note 3: Leakage current too great for any meaningful readings.

Note 4: Leakage current too great for any meaningful readings.

Note 5: Same as for Note 4.

Note 6: On four samples the twists did not fail but the oil and water concentration conducted from bottom end of twists and tripped breaker, at 7.5% concentration.

Note 7: Oil and 2.5% SSW solution conducts from electrode to electrode.

Note 8: Voltage from electrode to water globules and trips breaker.

Note 9: Voltage from electrode to electrode. Oil conducting.

Table 5

Dielectric Breakdown Strength of Magnet Wire Twists, in Air, in Oil, and in Oil Plus Percentage of Carbon Dust. (Lamp Black).

		0	.013 gms.	.026 gms.	.039 gms.	.052 gms.	.065 gms
Air	Formvar	10376.4					
	ML	11058.2					
A	Formvar	9942.0	11944.5	11235.6	10698.6	11464.4	12104.2
	ML	8839.9	10142.1	11058.1	10287.6	12263.0	12608.6
B	Formvar	14672.6	14943.6	13533.2	13832.3	12608.6	11571.8
	ML	12711.4	14411.1	13505.1	13860.1	14373.8	13225.0
C	Formvar	10974.2	10955.5	10423.2	10147.5	13822.8	12940.1
	ML	8606.2	16796.9	16849.0	16017.7	16961.0	14673.8
D	Formvar	12561.8	12398.4	12314.4	12529.1	11982.7	12776.8
	ML	10007.4	9363.0	10488.5	10908.5	10913.5	11824.1
E	Formvar	9722.6	10507.1	12057.5	12393.8	10497.7	13879.0
	ML	8634.4	10068.1	12940.2	14121.6	13416.6	14290.0
F	Formvar	10362.3	11623.4	13094.1	13351.4	13972.1	13598.8
	ML	8900.7	10516.3	11389.7	12263.0	12459.1	13052.2
G	Formvar	10633.2	11156.1	11207.5	11548.4	11459.6	11618.5
	ML	9465.7	9526.5	9834.6	9988.7	10348.4	10413.6
H	Formvar	11711.9	14121.8	13290.4	13122.3	12585.2	10903.9
	ML	8685.7	15345.1	16391.2	10325.0	11506.5	10465.2
I	Formvar	10040.2	11660.5	11698.0	12361.1	12109.0	12267.5
	ML	9549.7	10749.9	11399.1	11324.5	11394.4	11674.5
J	Formvar	10871.3	13094.5	12697.4	14103.1	14244.3	13542.7
	ML	8685.7	11216.8	12333.1	12478.0	12262.8	12958.8

Table 6

Dielectric Breakdown Strength of Magnet Wire Twists in Air, Oil, and in Oil Plus a Percentage of Simulated Sea Water and Amount of Carbon Dust.

			0	.25% SSW .013 gms	.5% SSW .026 gms	1% SSW .039 gms	2% SSW .052 gms	2.5% SSW .065 gms
Air	Formvar	10376.4						
	ML	11058.2	←Not Applicable→					
A	Formvar		9942.0	12333.1	11016.1	11076.8	10170.9	9703.7
	ML		8839.9	10465.1	10848.1	11258.9	9844.0	Arced
B	Formvar		14672.6	12122.9	12370.5	12664.5	12748.5	11599.9
	ML		12711.4	12893.5	11782.0	11277.6	11824.1	12248.9
C	Formvar		10974.2	11553.1	11553.1	9232.3	Conducts	
	ML		8606.2	11445.8	9731.8	7761.1		
D	Formvar		12561.8					
	ML		10007.4					
E	Formvar		9722.6					
	ML		8634.4					
F	Formvar		10362.3	11464.5	11347.5	9839.3	9045.3	8149.8
	ML		8900.7	10647.1	10493.1	10605.2	9769.3	9834.6
G	Formvar		10633.2	11651.2	10848.1	10679.9	9867.3	10773.4
	ML		9465.7	7910.5	8046.0	8961.3	7803.1	8713.8
H	Formvar		11711.9					
	ML		8685.7					
I	Formvar		10040.2	12188.3				
	ML		9549.7	12001.4				
J	Formvar		10871.3	10759.2	9339.5	9834.7	Conducts	
	ML		8685.7	10170.9	9689.9	9886.1		
K	Formvar		11370.9	9750.6	8615.7	8302.8		
	ML		10778.1	11165.5	9769.2	8564.3	←Conducts→	

Table 7

Dielectric Strength of Magnet Wire Twists, in Air, in Oil That Has Been Pressure Cycled, and Oil Plus a Percentage of Sea Water That Has Been Pressure Cycled. The Twists Were Pressure Cycled in the Oil and Its Combinations.

		Oil	P. Cyc. Oil	P. Cyc. Oil+.25%	P.Cyc.Oil +.5% SSW	P.C.Oil +1% SSW	P.C.Oil +2% SSW	P.C. Oil +2.5% SSW	P.C. Oil + 5% SSW
Air	Formvar	10376.4							
	ML	11058.2	← Not Applicable →						
A	Formvar	9942.0	9741.3	9008.0	9241.4	7817.1	3854.4	1625.1	Oil Conducted w/applied voltage, oil very cloudy
	ML	8839.9	9092.1	9297.7	10152.3	9190.2	8587.6	8573.8	
	Cycles	-90-	952	739	448	598	600	584	
B	Formvar	14672.6	12762.7	10418.3	9320.9	7518.3	Oil conducts with 2% solution Large amt of residue settles in container after sitting Appears similar to residue in 5606B		
	ML	12711.4	13608.0	12403.1	11870.8	9232.1			
	Cycles	-0-							
C	Formvar	10974.2	10231.7	9251.0	5617.5	7228.9	Voltage at 2% goes from el. to Gnd. To H_2O in bottom of Container		
	ML	8606.2	11263.7	9862.6	8630.6	7864.0			
	Cycles	-0-	574	555	589	543			
D	Formvar	12561.8	12253.9		7372.7	7359.4	6262.1	At 2.5% Concentration SSW conducts and trips breaker at approx. 3000 volts	
	ML	10007.4	10030.7	7560.3	6948.4	6841.1	6266.7		
	Cycles	-0-	576	744	800	594	557		
E	Formvar	9722.6	10469.8						
	ML	8634.4	9092.1						
	Cycles	-0-	665						
F	Formvar	10362.3							
	ML	8900.7							
	Cycles	-0-							
G	Formvar	10633.9	10605.3	7714.3	7438.9				
	ML	9465.7	8494.3	5949.3	5038.5				
	Cycles	-0-	546	563	611				
H	Formvar	11711.9							
	ML	8685.7							
	Cycles	-0-							
I	Formvar	10040.2							
	ML	9549.7							
	Cycles	-0-							

Table 8

Dielectric Strength of Magnet Wire Twists, in Oil, in Pressure Cycled Oil, and Pressure Cycled Oil Plus an Amount of Carbon Dust.

		Oil	P. Cy. Oil	P.C. Oil +.013 gms	P.C. Oil + .026 gms CD	P.C.Oil + .039 gms CD	P.C. Oil + .052 gm CD	P.C. Oil+ .065 gm CD
Air	Formvar	10376.4	Not Applicable					
	ML	11058.2						
A	Formvar	9942.0	9741.3	10390.4	11198.1	10483.7	11132.7	11020.6
	ML	8839.9	9092.1	9320.7	9704.0	9736.3	10198.8	9806.5
	Cycles	-0-	952	573	573	732	585	672
B	Formvar	14672.6	12762.7	14009.7	14350.5	13267.1	13673.5	13724.7
	ML	12711.4	13608.0	13804.0	14780.0	14191.6	14089.0	14084.5
	Cycles	-0-		543	688	601	643	701
C	Formvar	10974.2	10231.7					
	ML	8606.2	11263.7					
	Cycles	-0-	574					
D	Formvar	12561.8	12253.9					
	ML	10007.4	10030.7					
	Cycles	-0-	576					
E	Formvar	9722.6	10469.8					
	ML	8634.4	9092.1					
	Cycles	-0-	665					
F	Formvar	10362.3	11030.1	12123.0	12342.5	11581.2	11025.5	10586.3
	ML	8900.7	8447.5	10147.3	10740.4	9946.8	10058.7	9339.7
	Cycles	-0-	513	677	683	663	645	620
G	Formvar	10633.9	10605.3					
	ML	9465.7	8494.3					
	Cycles	-0-	546					
H	Formvar	11711.9	11441.0					
	ML	8685.7	8046.1					
	Cycles	-0-	446					
I	Formvar	10040.2		10670.5	11006.6	11561.9	11866.1	11445.8
	ML	9549.7		9988.8	10329.5	10796.5	10791.8	10577.1
	Cycles	-0-		613	639	709	673	636
J	Formvar	11114.1	10983.3	12552.1	11646.6	11431.7		
	ML	8667.2	8639.1	11753.9	10231.5	8452.3		
	Cycles	-0-	609	636	679	615		
K	Formvar							
	ML							
	Cycles							

Table 9

Insulating Materials in Fluids at Atmospheric Pressure and Room Temperature

	Material*	FLUID 6083	DC-200-1	Sunoco Transformer Oil	MS-1010
LAMINATES	Glass/Melamine/ Glass	No change in Dimensions	No change in Dimensions	No change in Dimensions	No change in Dimensions
	Glass/Epoxy/ Glass G-10	No change in Dimensions		No change in Dimensions	No change in Dimensions
	Glass/Silicone/ Glass	No change in Dimensions	No change in Dimensions	No change in Dimensions	No change in Dimensions
MAGNET WIRE	H. Formvar	No Failures	No Failures	No Failures	No Failures
	H. Poly-thermaleze	No Failures	No Failures	No Failures	No Failures
	H. Polyimide	No Failures	No Failures	No Failures	No Failures
LEAD WIRE	Hypalon Insulated	5.5% increase in diameter	No change in Dimensions, Fluid-Discoloring (Yellow)	10.3% increase in Diameter, Fluid-Discoloring (Amber)	6.3% Increase in Diameter, Fluid-Discoloring (Amber)
	Silicone Rubber Insulated	20% Increase in diameter 14.5% increase in length	47% Increase in Diameter 35% increase in length	14% increase in Diameter	15% Increase in Diameter
	Teflon Insulated	No change in Dimensions	No Change in Dimensions	No Change in Dimensions	No Change in Dimensions
	Teflon Insulated	No change in Dimensions	No change in Dimensions	No change in Dimensions	No Change in Dimensions
EPOXIES	Epoxylite 293-12	No change in Dimensions	2.6% Increase in Thickness	No Change in Dimensions	No Change in Dimensions
	Hysol C-26	No Change in Dimensions	No Change in Dimensions	No Change in Dimensions	3.95% Increase in Thickness
	3M 241	No Change in Dimensions Very Flexible	3.4% Increase in Thickness	No Change in Dimensions	No Change in Dimensions

*Materials in Fluids for Five Months.

Table 10

Motorette	Magnet Wire	Ground and Phase	Wedge	Varnish	Fluid	Insulation Characteristics
1				Silicone		
2	No. 20	Polyimide Varnish	Epoxy Glass	Modified		
3	H. Polyimide	Glass Cloth	Laminate	Polyester	MS-1010	
4			(G-10)	2-Dips and bakes		No appreciable change after 3 months in fluid
5				Silicone		Large change in dissipation factor after ½ hour in fluid
6	No. 20	Polyimide Varnish	Epoxy Glass	Modified	6083-B	
7	H.Polyimide	Glass Cloth	Laminate	Polyester		
8			(G-10)	2-Dips and bakes		
				Silicone	New Departure	
9	No. 20	Polyimide Varnish	Epoxy Glass	Modified	High Friction	No appreciable change after 4 months in fluid
10	H.Polyimide	Glass Cloth	Laminate	Polyester	MDE 14-1	
			(G-10)	2-Dips and bakes	Proprietary Fluid	

Table 11

Resistance and Dissipation Factors of Insulation Systems at Ambient Pressure

Oil Specification	MS-1010						MIL-H-6083B						NDE 14-1					
	Ground		Phase		Turn-to-Turn		Ground		Phase		Turn-to-Turn		Ground		Phase		Turn-to-Turn	
Time	IR	DF	IR	DF	IR	DF	IR	DF	IR	DF	IR	DF	IR	DF	IR	DF	IR	DF
Prior to submergence	31.6×10^6	1.7	11×10^6	2.4	2.0×10^5	1.6	5.6×10^6	1.4	4.9×10^6	2.9	2.2×10^5	1.7	7.8×10^6	1.4	4.6×10^6	2.0	2.1×10^5	2.7
After 30 minutes in oil	11.1×10^5	1.7	14.4×10^5	2.9	1.1×10^5	1.6	9.0×10^5	31.2	9.3×10^5	28.1	9.4×10^4	7.8	5.4×10^5	1.4	4.78×10^5	1.98	1.58×10^5	2.76
After 74 days in oil	12.8×10^5	1.2	17.9×10^5	2.0	1.1×10^5	1.9	6.8×10^5	42.5	6.3×10^5	36.3	7.8×10^4	16.3	-	-	-	-	-	-
After 114 days in oil	-	-	-	-	-	-	-	-	-	-	-	-	6×10^5	1.35	5.45×10^5	1.65	1.65×10^5	4.32

IR - Insulation Resistance, megohms (average of motorettes).
DF - Dissipation Factor, percent (average of motorettes).

Table 12

Switching and Circuit Interruption Devices

Mfgr.	Mfgr's No.	Vehicle	Voltage	Fluid	Comments
General Electric Co.	AK 2-25	Trieste	120V d.c.	Silicone 1 C.S.	Commercial Air Breaker similar to ACB
General Electric Co.	1C 2800 1622AM3AD	Trieste	120V d.c.	Silicone 1 C.S.	Main Line Contactor, 120V Coil
General Electric Co.	1C 2820 A100BB	Trieste	120V d.c.	Silicone 1 C.S.	Field Control Relay
General Electric Co.	1C 2820 E500A-20	Trieste	120V d.c.	Silicone 1 C.S.	Accelerating Contactor Flux decay type
General Electric Co.	TF J-600	Deep Quest	120V d.c.	Silicone 50 C.S.	Circuit Breaker
General Electric Co.	TE F-100	Deep Quest	120V d.c.	Silicone 50 C.S.	Circuit Breaker
Hartman	A754P	Star	115V d.c.	Primol 207	Battery Cut-off Single Pole
Hartman	A854C	Star	115V d.c.	Primol 207	Motor Reversing, 4 Pole
Hartman	BD241	Autec	60V d.c.	Silicone 1 C.S.	Magnetic Latching Contactor
Cutler Hammer	6041 H26A	NOTS Drive System	24V d.c.	Silicone 1 C.S.	

Table 13

Effect of 1000 high-voltage arcs on various fluids
(0.051" electrode gap)

	MIL-H-5606B Hydraulic Fluid	MIL-H-6083 B Hydraulic Fluid	VV-I-530a Insulating Oil	MS 1010 Lubricating Oil	MS-2110 TH Lubricating Oil	DC-200-1 Silicone	DC-200-10 Silicone	DC-200-50 Silicone	Primol 207 White Mineral Oil
Insulation Resistance, megohms, before arcing	1.6×10^{5} @71°F	1.7×10^{2} @71°F	4.0×10^{6} @77°F	3.2×10^{5} @7[illegible]°F	(Not complete)	3.8×10^{5} @76°F	1.8×10^{7} @80°F	3.9×10^{6} @77°F	6.3×10^{7} @79.5°F
IR, megohms, after 1000 arcs	1.5×10^{5} @72°F	1.4×10^{2} @74°F	1.4×10^{6} @81°F	3.6×10^{5} @74°F		3.4×10^{5} @74°F	7.2×10^{4} @82°F (2)	1.3×10^{5} @77°F (2)	5.1×10^{7} @80°F
Capacitance, microfarads, before arcing	0.36×10^{-4} @71°F	0.49×10^{-4} @71°F	0.35×10^{-4} @77°F	0.37×10^{-4} @78°F		0.35×10^{-4} @76°F	0.36×10^{-4} @80°F	0.32×10^{-4} @77°F	2.7×10^{-4} @79.5°F
Capacitance, microfarads, after 1000 arcs	0.36×10^{-4} @72°F	0.48×10^{-4} @74°F	0.36×10^{-4} @81°F	0.34×10^{-4} @74°F		0.36×10^{-4} @74°F	0.37×10^{-4} @82°F (2)	0.38×10^{-4} @77°F (2)	0.40×10^{-4} @80°F
Dissipation Factor, %, before arcing	1.8@71°F	43.5@71°F	1.2@77°F	1.0@78°F		0.0@76°F	0.0@80°F	0.0@77°F	0.0@79.5°F
DF, %, after 1000 arcs	1.8@72°F	56.5@74°F	2.0@81°F	1.6@74°F		0.0@74°F	0.0@82°F (2)	0.0@77°F (2)	0.0@80°F
Breakdown voltage, kv, ave. of first 5 arcs	18.9@71°F	25.0@73°F	20.7@78°F	20.5@78°F		28.3@72°F	14.8@80°F	6.3@78°F	27.6@79°F (0.060" gap)
Breakdown voltage, kv, ave. of last 5 of 1000 arcs	18.5@72°F	9.8@74°F	22.2@81°F	22.7@74°F		26.5@74°F	3.2@80°F (3)	Approx. 1.2@78°F (3)	16.1@69°F
Volume of solid breakdown products, cubic centimeters	0.045	0.10	0.04	<0.05		0.025	0.22 (2)	0.35 (2)	0.09
Viscosity @77°F, centistokes before testing	20	23	17	17	73	1.0	10	50	88

(1) This particular sample is not the standard reference fluid. Standard reference fluid is MIL-H-6083C.

(2) 200 arcs only.

(3) Average of last five of 200 arcs.

Table 14

Operation of Relays in Various Fluids, with 10 Amperes, 90 VDC, Load on Contacts
(Five Makes and Breaks per Minute)

	MIL-H-5606B Hydraulic Fluid	MIL-H-6083B(1) Hydraulic Fluid	VV-I-530a Insulating Oil	MS-1010 Lubricating Oil	MS-2110 TH Lubricating Oil	DC-200-1 Silicone	DC-200-10 Silicone	DC-200-50 Silicone	Primol 207 White Mineral Oil
Insulation Resistance of fluid, megohms, initially	1.5×10^{5} at 77° F	1.4×10^{2} at 77° F	2.6×10^{6} at 77.5° F	4.5×10^{5} at 76.5° F	(Not Complete)	1.1×10^{6} at 78° F	(Not Complete)	(Not Complete)	1.4×10^{7} at 76.5° F
IR of fluid, megohms, after 10,000 operations	8.5×10^{4} at 78° F	1.1×10^{2} at 80° F	6.5×10^{5} at 76° F	5.3×10^{4} at 77° F		1.7×10^{5} at 79° F			1.2×10^{7} at 77° F
Capacitance of fluid, microfarads, initially	0.37×10^{-4} at 77° F	0.48×10^{-4} at 77° F	0.37×10^{-4} at 77.5° F	0.36×10^{-4} at 76.5° F		0.35×10^{-4} at 78° F			0.37×10^{-4} at 76.5° F
Capacitance of fluid, microfarads, after 10,000 operations	0.35×10^{-4} at 78° F	0.53×10^{-4} at 80° F	0.36×10^{-4} at 76° F	0.35×10^{-4} at 77° F		0.36×10^{-4} at 79° F			0.36×10^{-4} at 77° F
Dissipation factor of fluid, %, initially	2.0 at 77° F	56.2 at 77° F	2.0 at 77.5° F	2.5 at 76.5° F		2.0 at 78° F			2.3 at 76.5° F
DF of fluid, %, after 10,000 operations	1.8 at 78° F	>60 at 80° F	1.8 at 76° F	1.7 at 77° F		1.9 at 79° F			1.7 at 77° F
Breakdown voltage of fluid, kv, initially (Average of 5 readings)-0.051-inch electrode gap	23.8 at 77° F	22.7 at 78° F	25.0 at 77° F	2.71 at 78° F		26.2 at 78° F			26.2 at 76.5° F
Breakdown voltage of fluid, kv, after 10,000 operations (average of 5 readings)-0.051-inch electrode gap	23.0 at 76° F	23.4 at 77° F	20.7 at 75° F	22.9 at 75° F		19.4 at 76° F			17.1 at 74° F
Volume of solid breakdown products, cubic centimeters, after 10,000 operations	0.05	0.10	0.08	0.25(2)		0.35			0.10
Duration of arc on opening contacts, seconds	0.008	0.0035	0.004	0.005		0.004			0.003
Approximate energy of arc on opening contacts, watt-seconds	1.8	0.79	0.90	1.1		0.90			0.68
Relay contact resistance, milliohms, initially	1.6-3.7	1.6-3.7	(Not measured for each test relay initially)						
Relay contact resistance, milliohms, after 10,000 operations	3.3-4.4	2.3-2.7	4.5-7.0	270(2)		2.2-11.3			2.3-12.9

(1) This particular sample is not the standard reference fluid. Standard reference fluid is MIL-H-6083C.

(2) Relay failed after 10,000 operations.

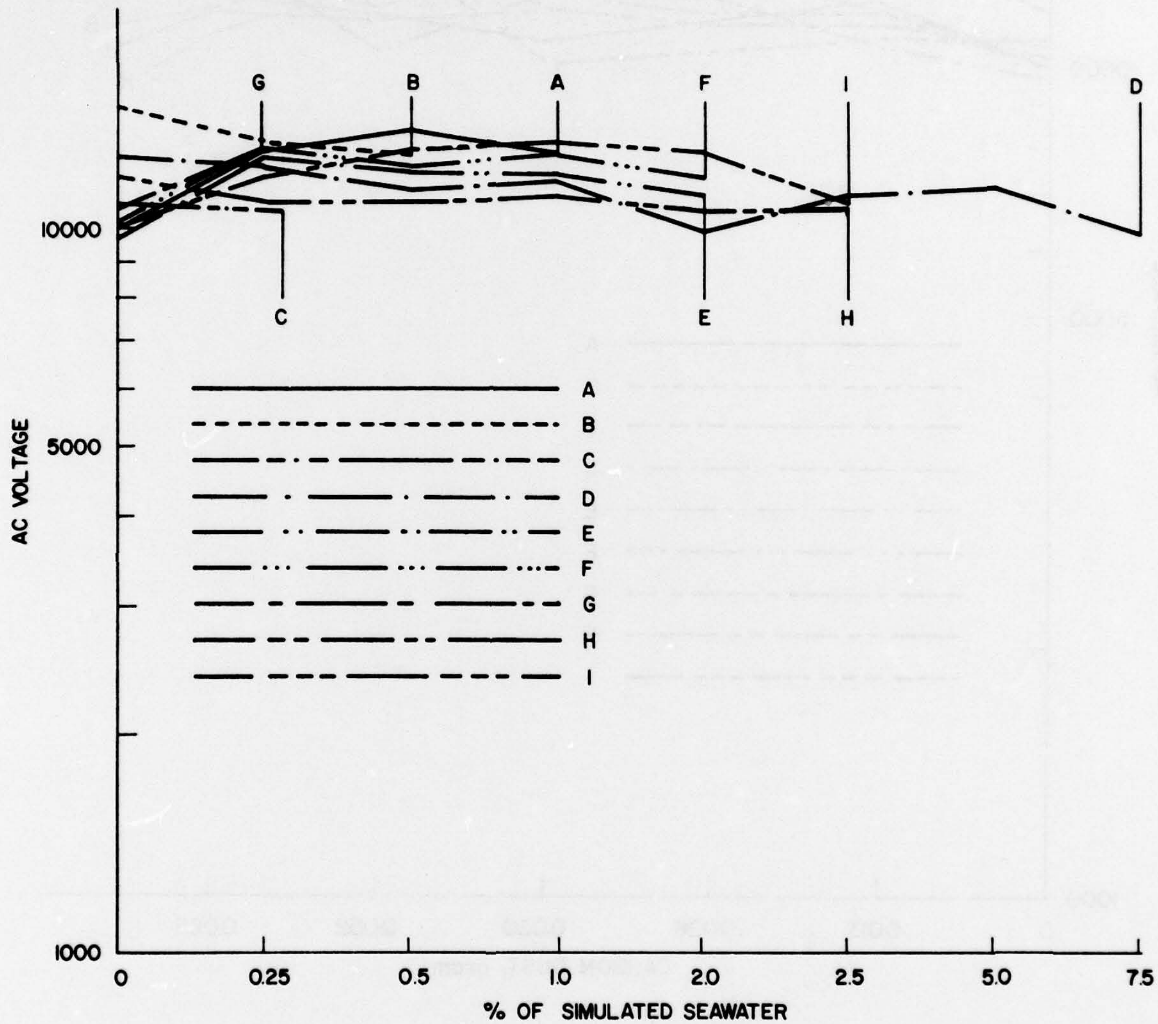


Figure 1
Dielectric Breakdown Strength of Formvar
in Oil Plus a Percent of Simulated Seawater

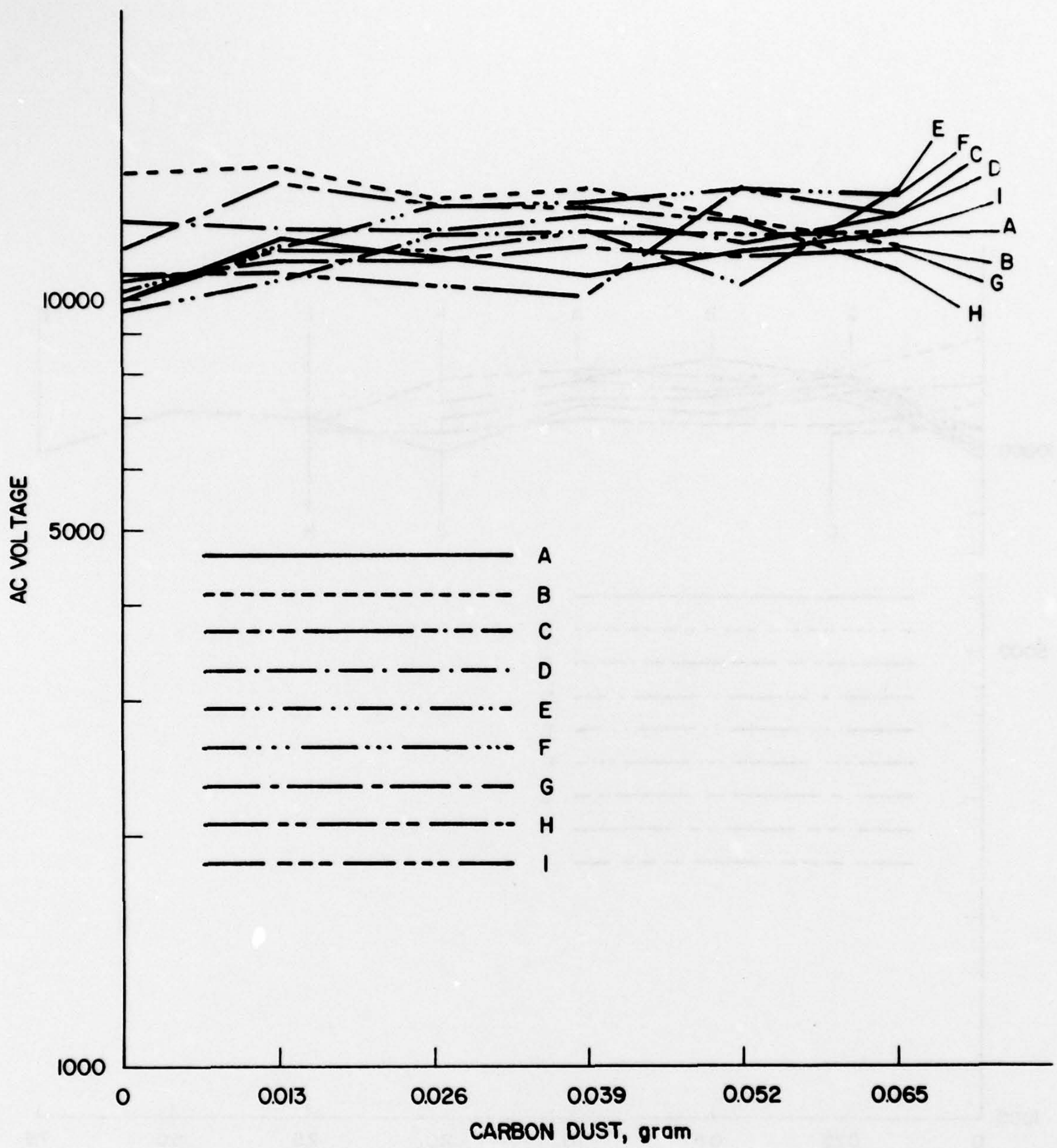


Figure 2
Formvar Twists in Oil and Carbon Dust

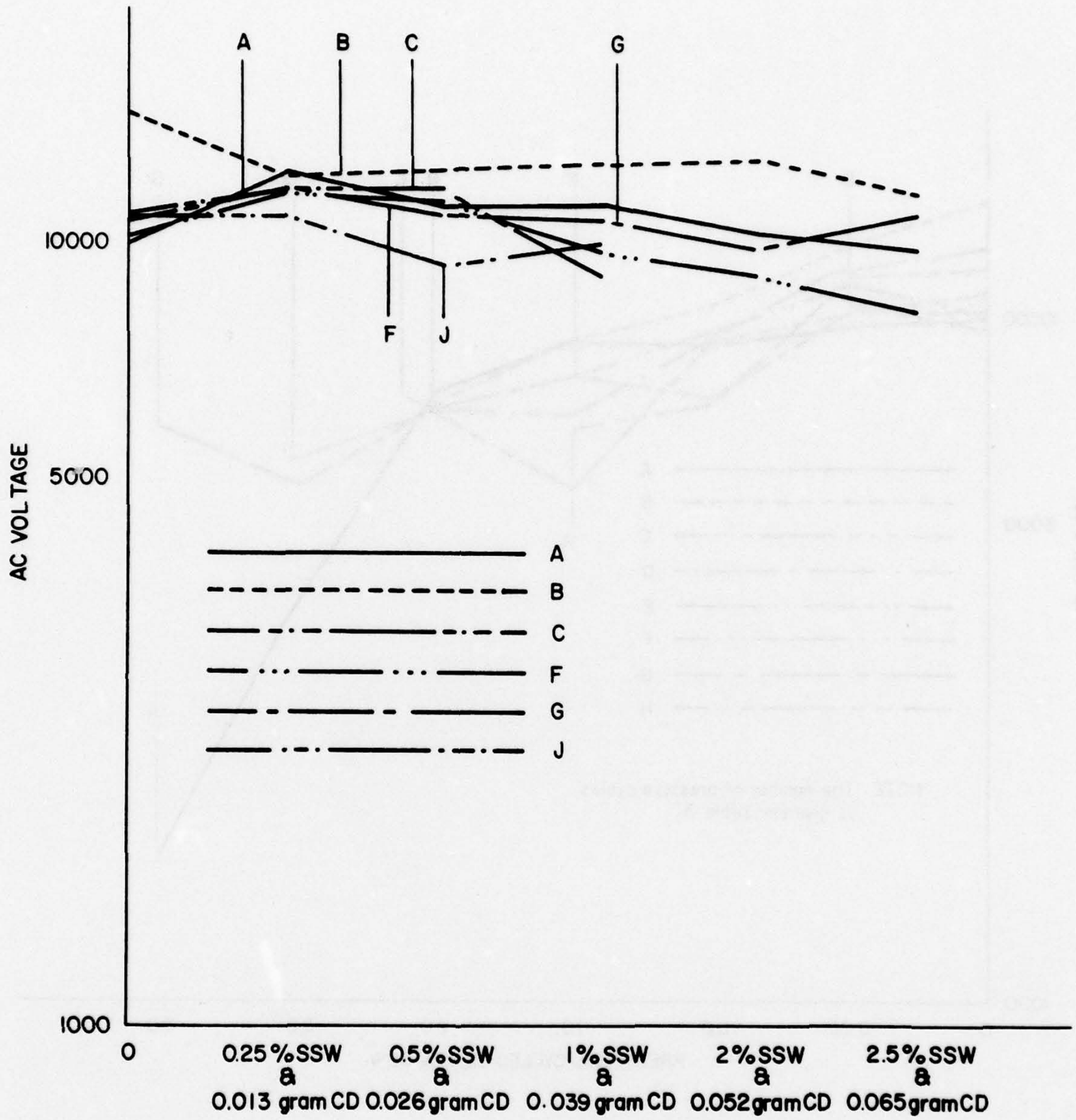


Figure 3
Electric Strength of Formvar Twists in Oil Plus a Percent of Simulated Seawater and a Percent of Carbon Dust

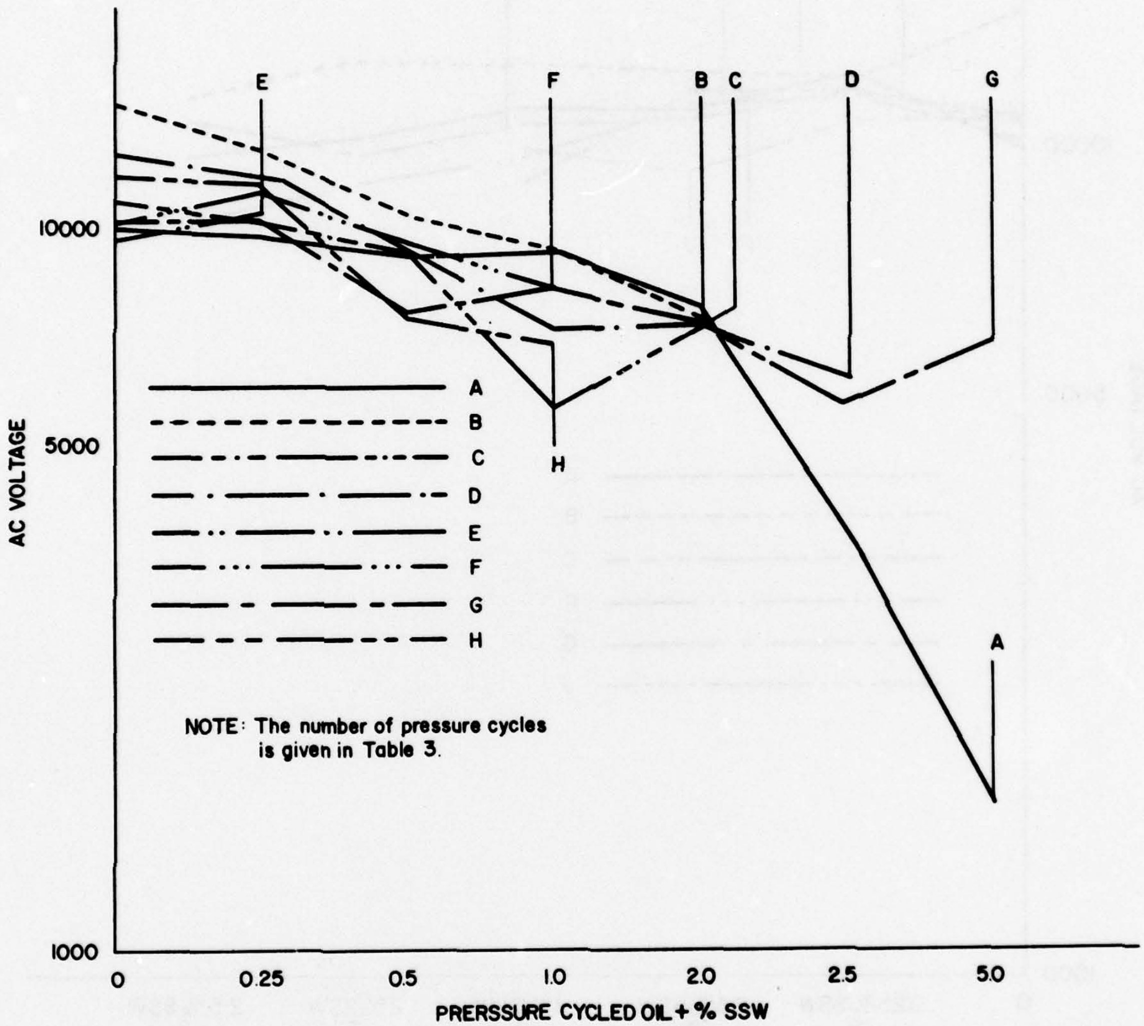


Figure 4
Dielectric Strength of Formvar in Oils
Plus Percent of Simulated Seawater That
Has Been Pressure Cycled

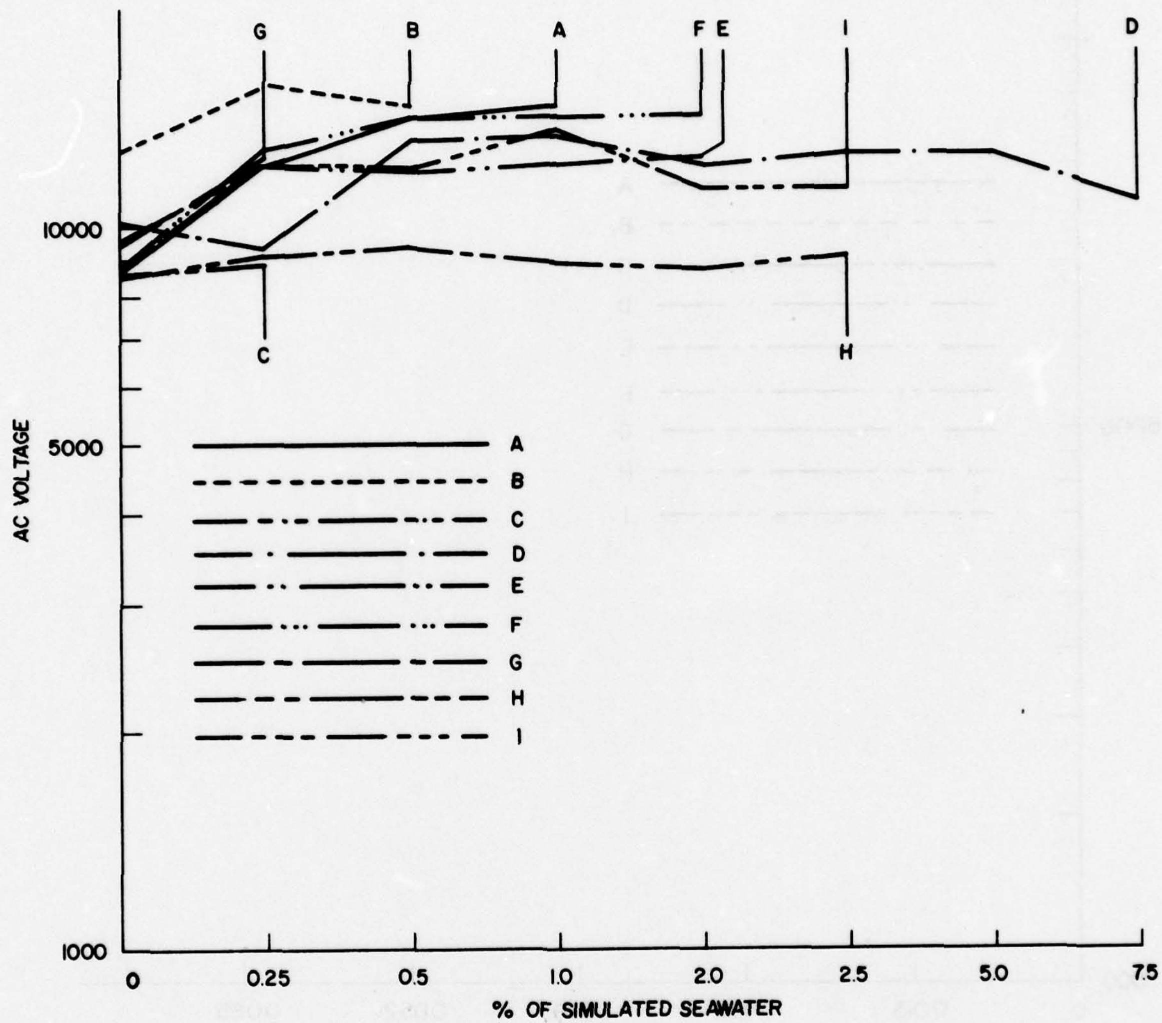


Figure 5
Dielectric Strength of ML Wire in Oil Plus
a Percent of Simulated Seawater

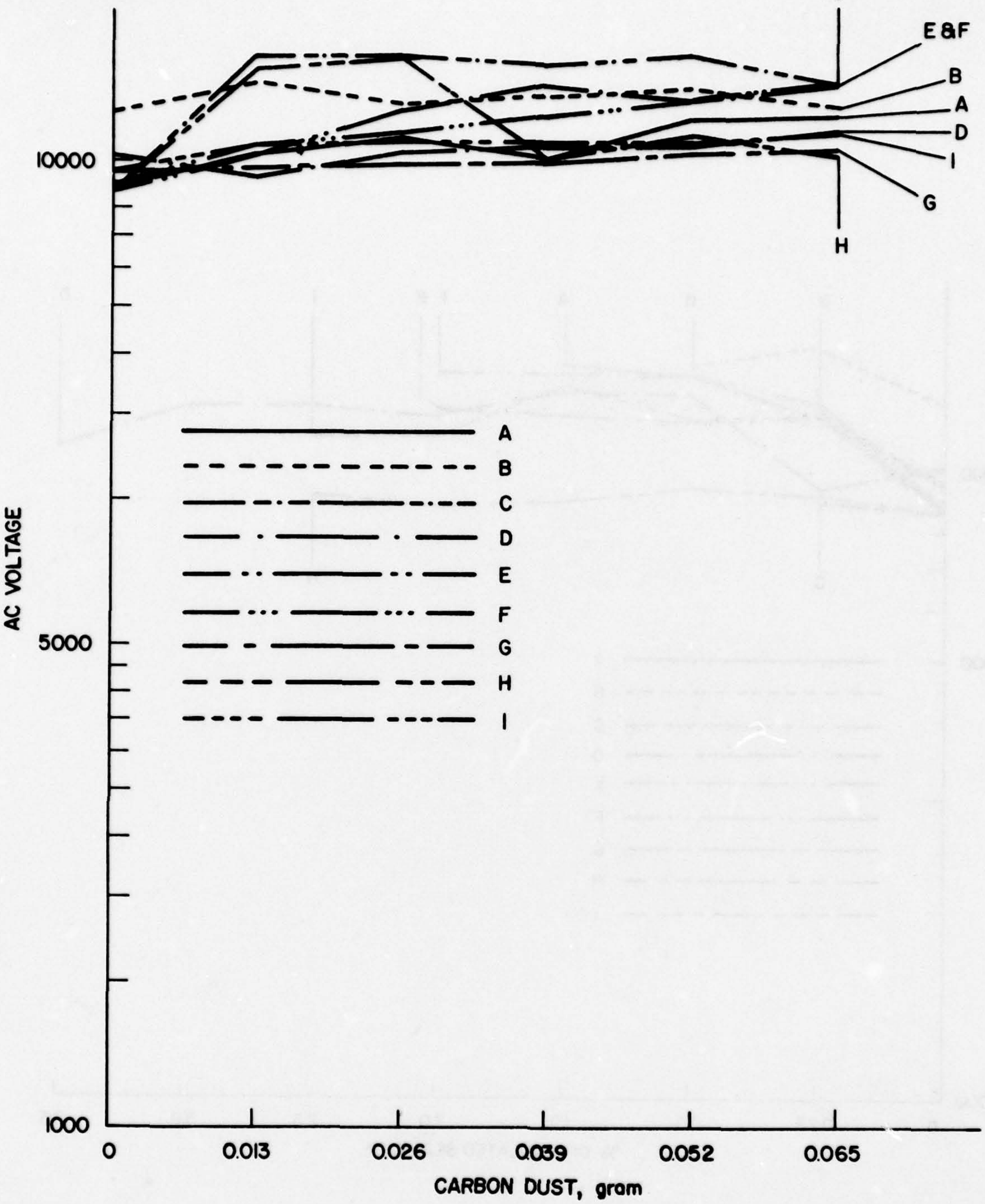


Figure 6
ML Twists in Oil and Carbon Dust

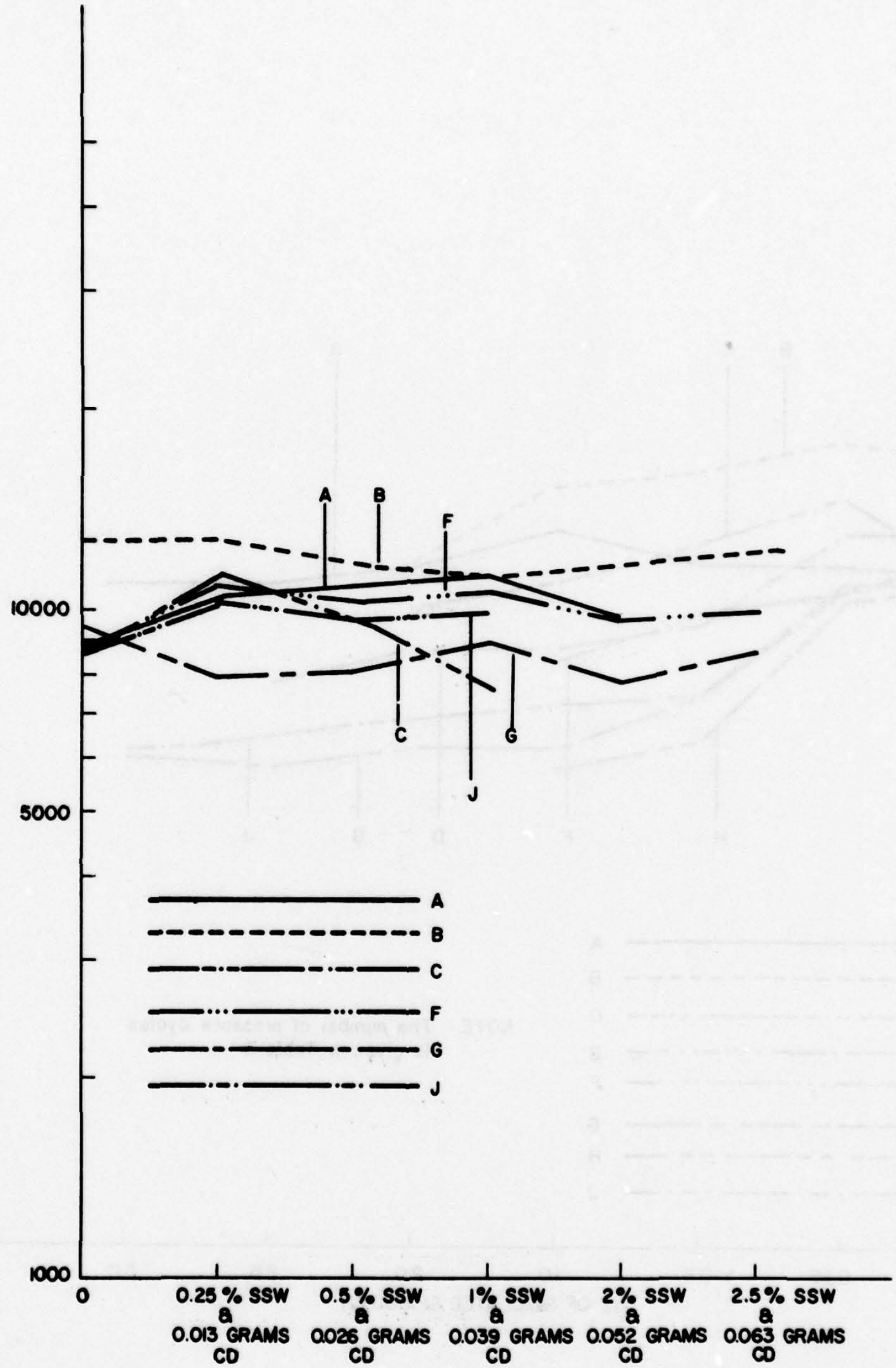


Figure 7
Dielectric Strength of ML Twists in Oil and in Oil Plus a Percent of Simulated Seawater and a Percent of Carbon Dust

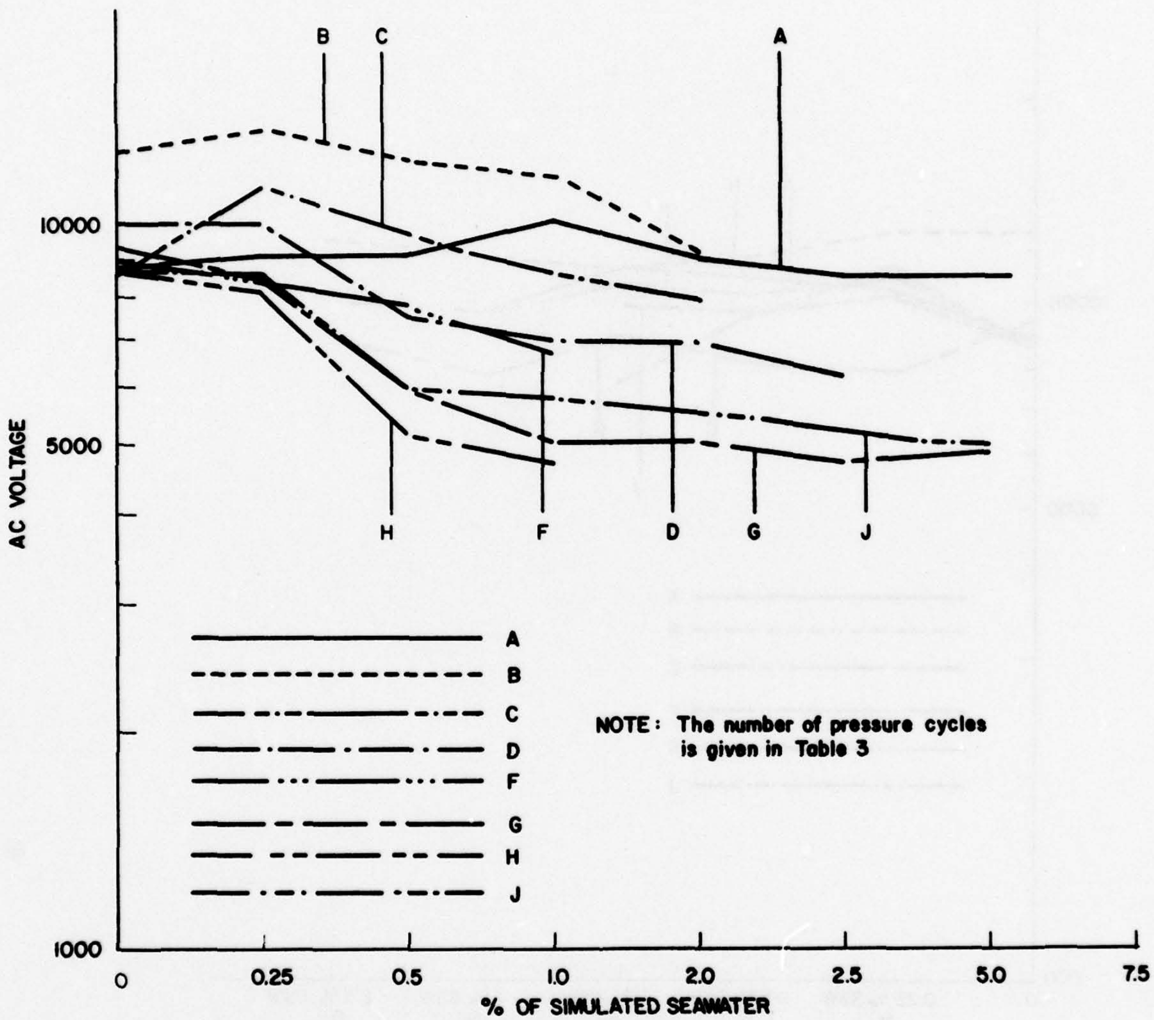
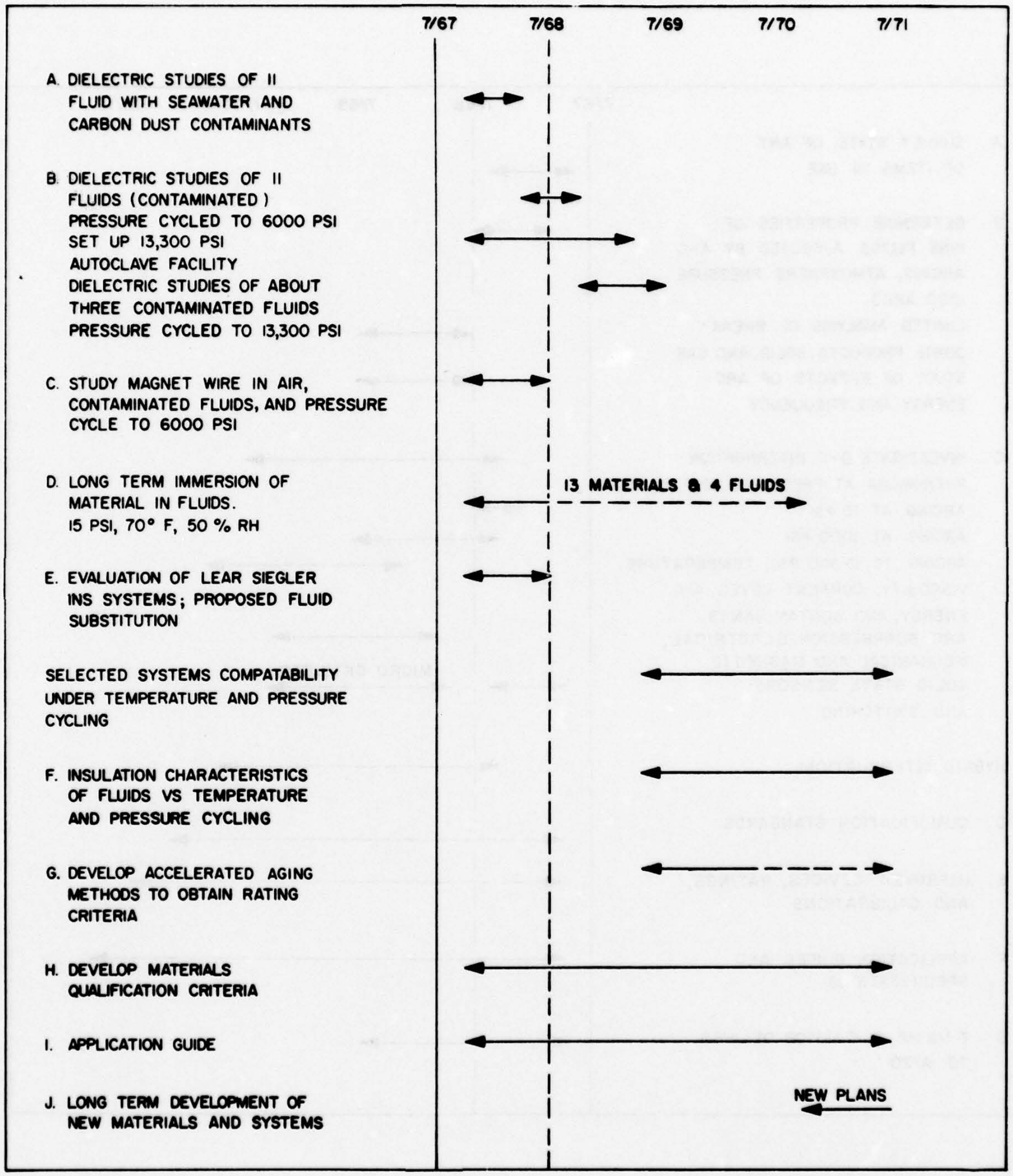


Figure 8
Dielectric Strength of ML Wire in Oils Plus a Percent of Simulated Seawater That Has Been Pressure Cycled

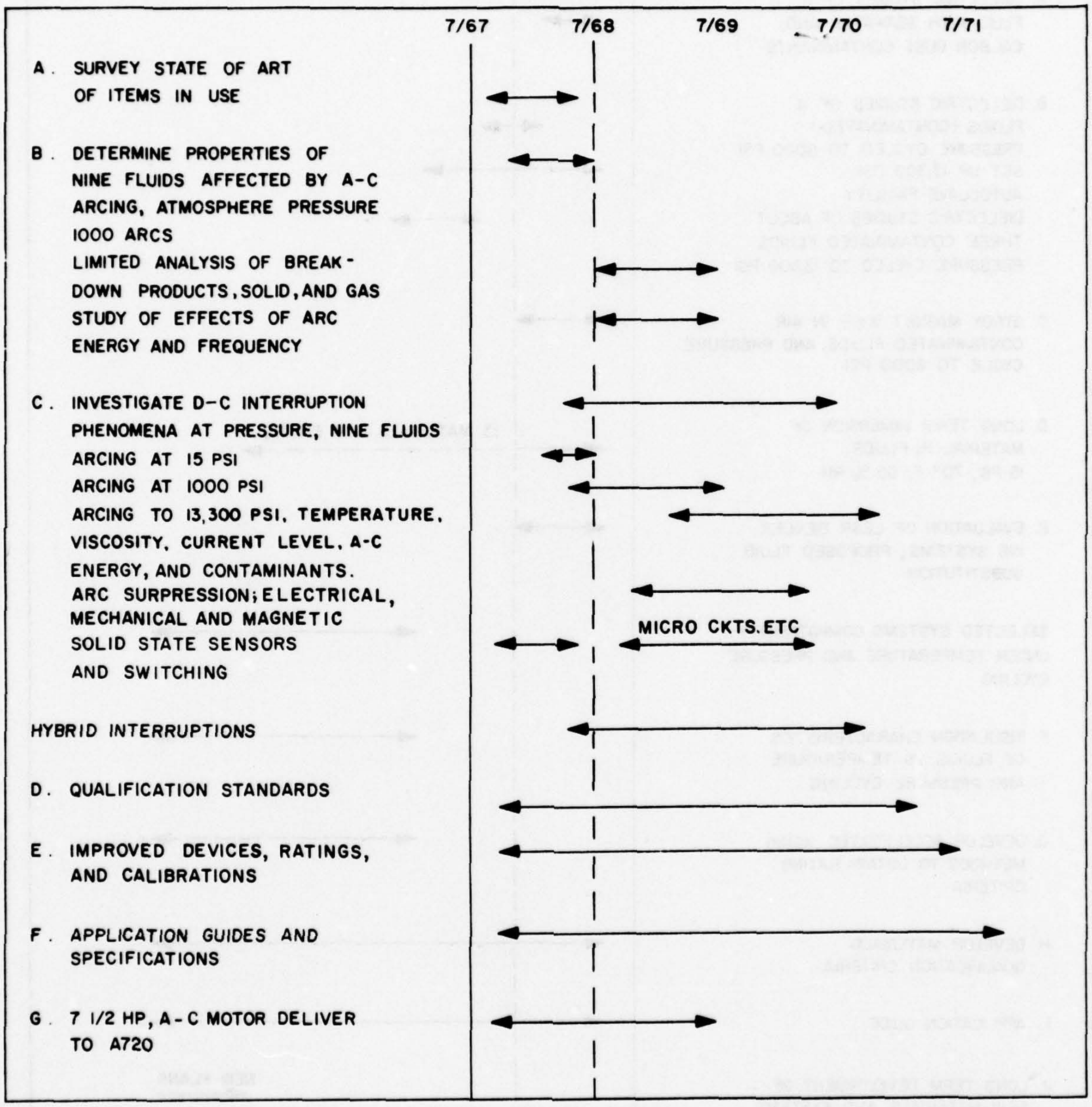
Annex I-5

DOT Project S-4728
Tasks 12317 and 12319

Task 12317


7/67
7/68
7/69
7/70
7/71
A. DIELECTRIC STUDIES OF 11 FLUID WITH SEAWATER AND CARBON DUST CONTAMINANTS
B. DIELECTRIC STUDIES OF 11 FLUIDS (CONTAMINATED) PRESSURE CYCLED TO 6000 PSI
SET UP 13,300 PSI AUTOCLAVE FACILITY
DIELECTRIC STUDIES OF ABOUT THREE CONTAMINATED FLUIDS PRESSURE CYCLED TO 13,300 PSI
C. STUDY MAGNET WIRE IN AIR, CONTAMINATED FLUIDS, AND PRESSURE CYCLE TO 6000 PSI
D. LONG TERM IMMERSION OF MATERIAL IN FLUIDS. 15 PSI, 70° F, 50 % RH
13 MATERIALS & 4 FLUIDS
E. EVALUATION OF LEAR SIEGLER INS SYSTEMS; PROPOSED FLUID SUBSTITUTION
SELECTED SYSTEMS COMPATABILITY UNDER TEMPERATURE AND PRESSURE CYCLING
F. INSULATION CHARACTERISTICS OF FLUIDS VS TEMPERATURE AND PRESSURE CYCLING
G. DEVELOP ACCELERATED AGING METHODS TO OBTAIN RATING CRITERIA
H. DEVELOP MATERIALS QUALIFICATION CRITERIA
I. APPLICATION GUIDE
J. LONG TERM DEVELOPMENT OF NEW MATERIALS AND SYSTEMS
NEW PLANS

Task 12319


7/67
7/68
7/69
7/70
7/71
A. SURVEY STATE OF ART OF ITEMS IN USE
B. DETERMINE PROPERTIES OF NINE FLUIDS AFFECTED BY A-C ARCING, ATMOSPHERE PRESSURE 1000 ARCS
LIMITED ANALYSIS OF BREAK-DOWN PRODUCTS, SOLID, AND GAS
STUDY OF EFFECTS OF ARC ENERGY AND FREQUENCY
C. INVESTIGATE D-C INTERRUPTION PHENOMENA AT PRESSURE, NINE FLUIDS
ARCING AT 15 PSI
ARCING AT 1000 PSI
ARCING TO 13,300 PSI, TEMPERATURE, VISCOSITY, CURRENT LEVEL, A-C ENERGY, AND CONTAMINANTS.
ARC SURPRESSION; ELECTRICAL, MECHANICAL AND MAGNETIC
SOLID STATE SENSORS AND SWITCHING
MICRO CKTS.ETC
HYBRID INTERRUPTIONS
D. QUALIFICATION STANDARDS
E. IMPROVED DEVICES, RATINGS, AND CALIBRATIONS
F. APPLICATION GUIDES AND SPECIFICATIONS
G. 7 1/2 HP, A-C MOTOR DELIVER TO A720

Enclosure (6)

MAY 1968 STATUS REPORT
DOT ELECTRICAL PENETRATORS AND CABLING SYSTEMS
FOR DEEP SUBMERGENCE APPLICATIONS
TASK AREA S4728, TASK 12321 WITH ANNEX I-6

Ref: (a) SFBNS ltr 9620/DOT (280 C) of 19 Dec 1967

Introduction. Reference (a) proposed a program of developing design, design standards, and installation procedures for the following outboard equipments for deep submergence applications:

01. Pressure hull or personnel sphere electrical penetrators.

02. Breakaway connectors for jettisonable electrical equipment.

03. Connectors which can be disconnected and reconnected underwater.

04. Junction boxes and cable splice methods.

05. Cable support and protection methods.

06. Penetrators for submerged low-pressure-resisting bulkheads.

Status. The Phase I effort, research of the state of the art, is proceeding. Table 1 lists the various agencies and companies contacted. For the purposes of this report the following items of interest are highlighted from trip reports of visits to Cannon, Vector, Southwest Research, Keystone Engineering, and Mecca.

01. Penetrators — ITT Cannon has a 36 wire penetrator for use with hull holes in the range of 3-4 inches in diameter. They have also provided part of a penetration system for the Autec program which E. B. has tested to 10-12,000 psi. This penetration is designed to mate with the ITT Cannon Std. line of MIL-C-24217 cable plug connectors and has a wire density of approximately twenty-four #16 wires. ITT Cannon has a proposal for a high pressure bulkhead feedthru. Crimped snap-in contacts are used with a potting compound seal. A resilient member is provided in the unit to allow the rear insulator to flex or breathe with cable column movement. This product is in the preliminary design stage. Vector cable (Marsh and Marine) has a line of Hull Penetrators which are currently being used for the LMSC Deep Quest and DSRV vehicles; so testing and operating data for them should be readily available in the near future.

02. Breakaway type connectors — Several companies have aerospace type breakaway connectors but very few hydrospace breakaway connector systems are available at the present time. Quick release lanyard mechanisms are available for piping and hose systems which might be adapted for electrical cable use.

Table 1

Letters Sent To		Replies and Info Received
For info and visit request		
I. T. T. Federal Labs	Nutley, N.J.	
General Products	Union Springs, N.Y.	X
Amphenol Borg	Broadview, Ill.	X
Deutch	Banning, Calif.	
D. G. O'Brien	Framingham, Mass.	X
Marsh and Marine	Houston, Texas	X
Electro Oceanics	Santa Monica, Calif.	
Mecca	Houston, Texas	
For info only		
Electric Boat — General Dynamics		
Westinghouse		
Joy Mfg.		
Times Wire and Cable		
Ceramaseal		X
Elco Corp.		
Cannon Electric		X
Bendix — (Scientella Division)		
U.S. Undersea Cable Corp.		X
Naval Ord. Test Station		
Naval Undersea Ord. Station		
Naval Research Lab		X
National Bureau of Standards		
Portsmouth Naval Shipyard		
TELCON — WHOI (re Alvin Systems)		

Some companies are making investigations into squib firing systems. An existing breakaway connector that shows some possibility is the torpedo release unit made by ITT Cannon which the Navy used. This unit is a flush-contact, spring-loaded, shear-pin, clamping mechanism which according to the vendor will work at 2000 psi. Further study of this unit will be made to determine if it can be used or adapted for deeper use.

03. Underwater make and break connectors —

a. So far, investigations have shown a lack of underwater make and break connectors.

b. ITT Cannon has a potential idea for one, but does not have any hardware yet. Vector has a unit which is in the process of being developed. It has a chamber that has water trapped inside after the making of the connection. This

chamber is then pumped full of non-conducting oil which displaces the water. The chamber must have the oil introduced at the top in order to evacuate the water, this makes it gravity or direction sensitive which is a disadvantage.

c. The oil industry has used make and break connections for years except they are the small pin insert types with single wires. These have been designed and used in marshes and pressure environments with apparent great success. This is an area which further study and investigation will be made.

04. Junction Boxes — This is an area again where users have in the past developed their own systems. Potted and oil compensating types are in the process of being studied. So far the compensated types appear to be bulky, the pin insert connections that the oil industry uses for deep well logging, etc. to 20,000 psi and 300°F temperature may show some promise if utilized in a way to take advantage of their rugged uses, and proven history of reliability.

05. Cable Protection Devices — This is another new area in the product world for deep pressures. Trough strapping materials, and foam materials are being looked at for their advantages and disadvantages.

In conjunction with electrical penetrators Subtask 01, a connector problem, identified as an EB DIV 14 pin (NR-1) connector is being studied. The problem is defined as conductor breakage in a modified MWF-14 cable, due to fatigue caused by the longitudinal motion of the conductor within the connector during pressure cycling. The pressure cycling value selected to provide a confidence factor for this application was 2000 cycles at 3000 psig. Failures were observed after approximately 260 cycles.

Job orders have been issued to Mare Island material Test Labs to provide two high pressure test tank systems. These include all the valves, gages and pumps necessary to reach a pressure of 30,000 psi. Cycling testing which is becoming more necessary will also be available using these 8- by 30-inch heavy walled tanks. A third tank of similar capacity will be available for our testing by about 1 June.

A job order has also been issued to provide a test-pull mechanism for connector and cable break away testing. Preliminary engineering and specification work has already been accomplished for this unit. Since the last report date, meaningful information has been obtained from visits and inspections of other facilities and industry. Copies of several companies' proposals for connectors and penetrators have been gathered. In some cases vendor testing reports will be available on these new products within the next several months.

A revised project schedule is given in Annex I-6.

Prospective Procurements. Comparisons are being made between vendors products and a good cross sample will be purchased and tested. Most of the existing products are fairly easy to obtain. As soon as enough differences in methods of construction and materials can be obtained, testing will be originated on a greater scale than at present.

Actual procurements

ITT Cannon Electric Co:

1. 2 each — P/N H102051
2. 2 each — P/N H102051-1
3. 4 each — P/N H102052-5

Vector Cable Co:

1. 1 each — P/N RM 4 MP — Furnish with 18-inch cable.
2. 1 each — P/N RM 4 FS — Furnish with 18-inch cable.
3. 1 each — P/N RM 4 MLS #71-077 — Furnish with 18-inch cable.
4. 1 each — P/N RM 4 FLS #71-079 — Furnish with 18-inch cable.
5. 1 each — P/N RMS 4S MLS #71-097 — Furnish with 18-inch cable.
6. 1 each — P/N RMS 4S FLS #71-092 — Furnish with 18-inch cable.

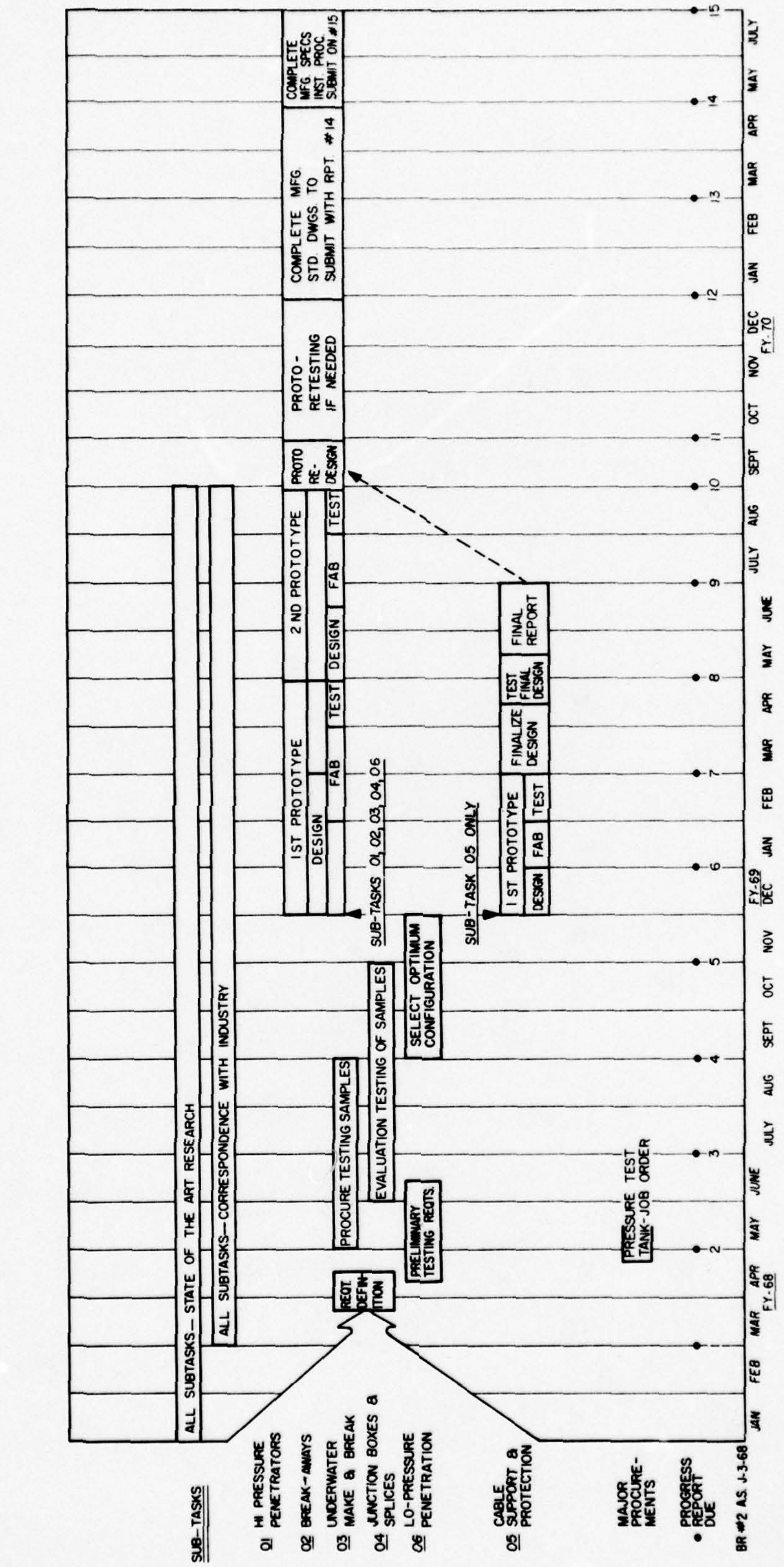
Kemlon products:

1. 2 each — P/N 16-A-45, Description: K-25-CF. Neoprene insulated assembly. Furnish with 2-foot Kemlon 141C cable.
2. 2 each — P/N 16-A-44, Description: K-25-CM. Neoprene insulated assembly. Furnish with 2-foot Kemlon 141C cable.
3. 2 each — P/N 16-A-57 K-25-F 3 in 1. Neoprene insulated assembly. Furnish with 2-foot cable.
4. 2 each — Complete Neoprene insulated assembly to mate with P/N 16-A-57. Furnish with 2-foot cable.
5. 2 each — P/N 16-A-102 K-30-BM Coax. Neoprene molded insulated assembly. Furnish with 2-foot cable.
6. 2 each — Complete Neoprene insulated assembly to mate with P/N 16-A-102. Furnish with 2-foot cable.

Annex I-6

May 1968

DOT Project S-4728, Task 12321


SUB-TASKS
01 HI PRESSURE PENETRATORS
02 BREAK-AWAYS
03 UNDERWATER MAKE & BREAK
04 JUNCTION BOXES & SPLICES
06 LO-PRESSURE PENETRATION
05 CABLE SUPPORT & PROTECTION
MAJOR PROCUREMENTS
• PROGRESS REPORT DUE
BR #2 A.S. J-3-68
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JULY
FY-68
FY-69
FY-70
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
ALL SUBTASKS— STATE OF THE ART RESEARCH
ALL SUBTASKS—CORRESPONDENCE WITH INDUSTRY
REQT. DEFIN-ITION
PROCURE TESTING SAMPLES
EVALUATION TESTING OF SAMPLES
PRELIMINARY TESTING REQTS.
SELECT OPTIMUM CONFIGURATION
PRESSURE TEST TANK-JOB ORDER
SUB-TASKS 01, 02, 03, 04, 06
1 ST PROTOTYPE
DESIGN
FAB
TEST
2 ND PROTOTYPE
DESIGN
FAB
TEST
PROTO RE-DESIGN
PROTO-RETESTING IF NEEDED
COMPLETE MFG STD DWGS TO SUBMIT WITH RPT #14
COMPLETE MFG SPECS INST. PROC SUBMIT ON #15
SUB-TASK 05 ONLY
1 ST PROTOTYPE
DESIGN
FAB
TEST
FINALIZE DESIGN
TEST FINAL DESIGN
FINAL REPORT

Enclosure (7)

MAY 1968 STATUS REPORT
DOT ELECTRIC CABLES FOR DEEP SUBMERGENCE VEHICLE APPLICATIONS
TASK AREA S4728, TASK 12314 WITH ANNEXES I-7 AND II-7

Ref. (a) NASL Task Summary, Task 12314, dated 1 Nov 1967

Introduction. The objective of this project is to develop a family of electrical cables suitable for use on deep submersibles, present and contemplated for the time period through 1975. The detailed project information is contained in the Laboratory Program Summary, reference (a).

A preliminary investigation was made on shielded cables for pan and tilt devices to improve the flexing endurance when exposed to hydrostatic pressure. This resulted in an improved cable by substituting a served shielded cable (one in which the strands are wound helically with minimum crossover), for the conventional braided shielded cable. This work on an immediate problem resulted in a temporary solution which will be reported in detail under separate correspondence. It is anticipated the NASL development will result in flexible shielded cables recommended for high cyclic life to 20,000 foot depths with a minimum of special protective and supporting structures.

Initial investigations on five types of modified outboard submarine cables and two standard Navy-type cables were made for the following:

- Dielectric withstanding capability.*
- Insulation resistance.*
- Capacitance.*
- Bending endurance at 28° F.
- Capacitance stability under prolonged constant hydrostatic pressure and at increments of pressure.
- Longitudinal water leakage at maximum pressures of 1500 psi.

Analysis of the data acquired led to the conclusion that the electrical characteristics of cables are in fact affected by pressure cycling and by prolonged static pressure.

*Cables submerged in water at atmospheric pressure.

With the cooperation of ANNADIV NSRDC, which supplied the DOT reference fluids, NASL evaluated the compatibility of the materials contemplated for use as the outer jacket of cables with these fluids. The fluids were:

L-582*	MIL-H-5606B	hydraulic oil
L-597*	VV-I-530	transformer oil
L-633*	MIL-H-6083C	hydraulic oil
L-632*	MIL-L-17672	turbine oil
L-587*	MIL-S-21568A	silicone oil ICS
L-575*	VV-D-001078	silicone oil ICS

*NSRDC Annapolis Materials Lab Identification No.

The jacket materials were:

Artic Neoprene applied by Boston Insulated Wire & Cable Co.

Artic Neoprene applied by unspecified manufacturer.

Vinyl (unspecified)

Polyurethane (unspecified)

Nitrile Rubber (unspecified)

Testing consisted on placing five specimens of each of the jacket materials into each of the six fluids, for a period of 58 days at room temperature. Tests for tensile strength, elongation, hardness, and by infrared spectrophotometry were made at the beginning and at the end of the period. Hardness tests and spectrophotometry were also conducted at intervals during the period but results are not reported at this time. Data on tensile and elongation indicate the following conclusions:

- The vinyl and the nitrile rubber were degraded most, becoming hard and stiff.

- The neoprenes were degraded most by the transformer oil and the MIL-H-5606B oil.

- The polyurethane was not significantly degraded by any of the fluids.

In December 1967, at the behest of Naval Ship Systems Command, NASL prepared a basic set of tables for tentative types of power, control, communication, video- and radio-frequency functions, for deep-submergence vehicle application. The tables show an array of conductor sizes, conductor quantities and expected gross weights and diameters.

The establishment of test facilities has the following status:

- A tank measuring 3 inches inside diameter (ID) x 20 feet long for pressure cycling has been ordered and is scheduled to commence operation in July 1968.

- A tank measuring 5 inches ID x 20 feet long for prolonged static pressure is being ordered.

- A tank measuring 18 inches ID x 5 feet long for manipulating cable samples under pressure is being ordered.

NASL is rendering assistance to current deep-submersible programs as the need arises, with regard to the design of cables and cable assemblies.

The detail results of the areas investigated are imparted with conclusions in Annex I-7.

A schedule of the two detail investigations on this project is presented in II-7.

Annex I-7

May 1968 Status Report

DOT Electric Cables for Deep Submergence Applications

Results

The study made on cables for deep submergence applications indicated current and anticipated operational needs and problems. Some of the problems reported have been investigated and are reported herein. Additional investigations are included to obtain engineering information on standard Navy outboard submarine cables and modified cables for input on future designs of cables for deep submergence use. The results of this work follow:

a. Electrical measurements on 20-foot lengths of the five modified cables, purchased by the Laboratory from the Boston Insulated Wire and Cable Company, Table I7-1, showed the following:

Proof Voltage Withstood

	Required Proof Voltage, kv			
Cable Type	Cond to Cond	Cond to Shield	Shield to Water	Shield to Shield
EBDS-2SWU-1-MOD	2	1	0.5	-
EBDS-2SWU-4-MOD	2	1	0.5	0.2
EBDS-THOF-3-MOD	2	-	-	-
EBDS-THOF-42-MOD	2.5	-	-	-
EBDS-MWF-24-MOD	3.0	-	-	-

Cond - Conductor

Insulation Resistance and Capacitance

Cable Type		Insulation Resistance megohms-1000ft Max	Min	Avg	Capacitance, Picofarads/ft Max	Min	Avg
EBDS-2SWU-1-MOD	Cond to other and Shield	11,200	1,100	6,100	52.5	52.4	52.4
	Both Conds to Shield	-	-	-	-	-	89.0
	All to Water	-	-	-	-	-	128.0
EBDS-2SWU-4-MOD	Cond to other and Shield	15,500	11,500	13,500	48.8	46.8	47.8
	Both Conds to Shield	7,700	6,700	7,200	81.9	78.0	80.7
	All to Water	-	-	1,700	-	-	303.0
EBDS-THOF-3-MOD	Cond to Others and Water	20,000	17,300	18,200	47.7	47.6	47.6
	All to Water	-	-	6,800	-	-	104.0
EBDS-THOF-42-MOD	Cond to Others and Water	8,000	6,000	7,000	87.8	85.4	86.9
	All to Water	-	-	2,200	-	-	173.0
EBDS-MWF-24-MOD	Cond to Others and Water	18,000	200	4,000	50.5	45.4	48.4
	All to Water	-	-	500	-	-	320.0

Note: The above measurements were taken with an 18-foot length of the cable sample submerged in water at atmosphere pressure and at room temperature of 24° to 26° C.

b. Longitudinal water leakage measurements on 5-foot lengths of the modified cables showed the following:

Cable Type	Longitudinal Water Leakage, cubic inches: Watertightness**	Hydrostatic Pressure *: 500 psi	1000 psi	1500 psi
EBDS-2SWU-1-Mod	0	1.2	0.1	0
EBDS-2SWU-4-Mod	0.5	0	0	0
EBDS-THOF-3-Mod	0	0	0	0
EBDS-THOF-42-Mod	0	100+	-	-
EBDS-MWF-24-Mod	55.8	0	0	0

* Water leakage after 2 hours at each pressure; cable held in a double-ended constricting packing tube.

** Water leakage after 6 hours at 25 psi; cable held in a non-constricting packing tube, in accordance with paragraph 4.8.9 of reference (e).

Notes: 1 - Water leakage through the 2SWU-4 and MWF-24 cables at 25 psi, occurred mostly under the binder tape.

2 - Water leakage through the 2SWU-1 cable occurred under the outer cable sheath.

3 - Water leakage through the THOF-42 cable occurred between the conductors. The test was discontinued after 2 hours at 500 psi.

c. The change in capacitance values in cables with the application of an external hydrostatic pressure of up to 2000 psi was measured on 20-foot lengths of four of the modified cables and a standard Navy MWF-24 cable. An 8-foot length of standard Navy DSS-3 cable with a molded plug attached to one end of the cable and the other end of the cable potted in an epoxy compound was subjected to pressures of up to 5000 psi. The modified cables were each packed in two double-ended packing tubes and installed in a pressure tank, with approximately 17 feet of cable in the tank. The results of these measurements appear in Figure I7-1 and show that there is an increase in capacitance between the individual conductors as follows:

Type Cable	200 psi	1000 psi	2000 psi
	% Capacitance increase under pressure		
EBDS-2SWU-1-Mod	2.6	4.5	4.8
EBDS-2SWU-4-Mod	0.3	2.5	2.8
EBDS-THOF-3-Mod	2.6	3.5	4.0
EBDS-MWF-24-Mod	0.3	0.5	-
Standard Navy MWF-24	1.4	2.6	-
Standard Navy DSS-3	0	2.1	3.2

d. The compatibility of cable jacket compounds with pressure compensating fluids was investigated by placing specimens of five jacket compounds in six different fluids for a period of 58 days at room temperature. Five dumbbell-shaped specimens of each jacket compound were placed in individual beakers containing approximately 400 ml of fluid. Measurements of tensile strength, hardness, and infrared spectra were taken before and after the 58-day immersion period. The hardness and infrared measurements were also taken during the period to check for changes in the jacket compounds and the fluids. The hardness and infrared measurements will be reported in a later report. The tensile strength and elongation measurements, shown in Table I7-2, indicated the following:

(1) The vinyl and nitrile rubber jacket compounds were affected most severely by the fluids investigated. They were hardened and stiffened.

(2) The arctic neoprene compounds were affected most severely by the transformer oil and petroleum base fluid (L582).

(3) The polyurethane jacket compound was not significantly affected by any of the fluids.

e. Following receipt of a verbal report that cable sheaths had been known to develop cracks under pressure, samples of arctic polychloroprene and a compound containing natural rubber were subjected to hydrostatic pressure of 10,000 psi. Specimens were prepared 2 x 1/4 x 1/16-inch thick and bent around 1/8-inch diameter mandrels. The specimens were held in the bent position and suspended in a pressure tank. The pressure was raised to 10,000 psi and held for periods of 3 hours, 1 day, and 8 weeks. The pressure was slowly released (approximately 3 minutes) and the specimens were visually examined weekly. The arctic polychloroprene and natural rubber compounds showed no evidence of any cracks developing in the stressed surface after 10 cycles in a 2-month period.

f. Long term water immersion of a 9-foot length of the EBDS-2SWU-1-Mod cable showed the following:

(1) The capacitance between conductors and shield increased less than 6% during the first pressure cycle to 5000 psi , with the greatest part of the change occurring within the first 500 psi pressure increase. The capacitance, after releasing the pressure, was approximately 2% higher than "as received," suggesting a set in the cable components.

(2) Subsequent pressure cycles during a 7-week period, with the cable in water at atmosphere pressure between the pressure cycles, showed only a slight further capacitance increase to less than 7% of the original value.

(3) With the pressure maintained at 5000 psi for an additional 2-week period, the capacitance increased to approximately 8% of the original value. When the pressure was released, the capacitance was approximately 6% higher than the "as received" value.

g. Five different shielded pair cables were flexed in a chamber at 28° F, by a CTFM sonar drive unit, to rotate in a horizontal plane $\pm 120°$ from the neutral position. The principal features of the cables are described as follows:

Sample	Type	Manfacturer	Watertight Construction	Filler	Shield
A	DSS-3	Simplex Wire & Cable Co.	Yes	Elastomeric	Braided Copper
B	"Bronco 66"	Western Insul. Wire Co.	No	Rope fibers	Braided Copper
C	-	Winsco Co.	Yes	Duxseal	Metalized Mylar tape, Drain Wire
D	-	South Bay Cable Corp.	Yes	Elastomeric	Open Weave Rocket Wire
E	-	Boston Insul. Wire & Cable Co.	Yes	Elastomeric	Braided Copper

Specimens of the above samples were flexed in pairs, set up in three different configurations with the shield resistance monitored during flexing, and showed the following:

(1) Samples A and B, suspended in a vertical position with the paired cables twisted two turns in a 22-inch length, showed evidence of shield failure in 300 and 1000 cycles, respectively.

(2) Samples A and B, suspended in a vertical position with the paired cables in parallel for a 20-inch length, showed evidence of shield failure in 1000 and 2100 cycles, respectively.

(3) Samples B, C, D, and E, held parallel for a 25-inch length within a flexible plastic tubing and supported in a flat spiral shape, showed evidence of shield failure at approximately 125,000, 220,000, 240,000 (+)*, and 15,000 cycles, respectively.

(h) A proposed tentative list of cables for deep submergence applications is shown under Table I7-3. This list includes cable types, conductor size range, overall diameter, capacity and weight.

* Flexing discontinued, no change in shield resistance.

Table I7-1
Description and Construction of Cables
Boston Insulated Wire and Cable Co.

1. TYPE EBDS-2SWU-1-MOD

Diameter over stranded conductor, inch	0.049
Conductor - 7 strands x 0.016-inch coated copper.	
Strand interstices filled with a black plastic compound.	
Diameter over insulated conductor, inch	0.115
Insulation consisted of a black rubberlike compound resembling butyl rubber, average thickness 0.033-inch	
Diameter over Nylon jacket, inch	0.127
1 conductor covered with a clear nylon, other conductor covered with a white nylon. Thickness of nylon jacket-approximately 0.006-inch	
Valley sealing compound - cream colored elastomeric compound.	
Diameter over twisted pair of conductors, inch	0.192
Lay of twisted pair - 2-1/2-inch left hand.	
Manufacturer's Identification Tape: Cream colored tape located along void of twisted conductors.	
Diameter over separator type, inch	0.199
Separator type consisted of a transparent film tape coated with a black rubberlike compound, 0.012-inch thick x 1/2-inch wide, 1/8-inch lap, right-hand lay.	
Diameter over braided shield, inch	0.224
Shield consisted of braided copper, 0.0065-inch diameter coated copper strands, 6 strands per carrier, 24 carriers, 2 over - 2 under weave, 9.6 picks per inch.	
Diameter over inner jacket, inch	0.332
Inner jacket consisted of a black rubberlike compound resembling butyl rubber.	

Jacket thickness, inch	Max - 0.077 Min - 0.045 Avg - 0.060

Diameter over outer jacket, inch 0.416

Outer jacket consisted of a black rubberlike compound resembling arctic polychloroprene.

Jacket thickness, inch	Max - 0.045 Min - 0.041 Avg - 0.043

Printing on outer jacket in white letters 1/8-inch high, EBDS-2SWU-1-MOD, at 10 1/2-inch intervals

NOTE: There was no adhesion between the inner and outer jackets.

2. TYPE EBDS-2SWU-4-MOD

Diameter over stranded conductor, inch 0.049

Conductor - 7 strands x 0.016-inch coated copper.

Strand interstices filled with a black plastic compound.

Diameter over insulated conductor, inch 0.113

Insulation consisted of a black rubberlike compound resembling butyl rubber, average thickness 0.032-inch

Diameter over Nylon jacket, inch 0.125

1 conductor covered with a clear nylon, other conductor covered with a white nylon. Thickness of nylon jacket-approximately 0.006 inch

Valley sealing compound - Cream colored elastomeric compound.

Diameter over twisted pair of conductors, inch 0.191

Lay of twisted pair - 2 1/2-inch, left hand

Diameter over separator tape, inch 0.207

Separator tape consisted of a transparent film tape coated with a black rubberlike compound, 0.012-inch thick x 1/2-inch wide, 1/8-inch lap, right-hand lay.

Diameter over braided shield, inch	0.231

Shield consisted of braided copper, 0.0065-inch diameter coated copper strands, 6 strands per carrier, 24 carriers, 2 over - 2 under weave, 9.6 picks per inch. The braided shield was filled with a black plastic compound.

Separator tape over braided shield consisted of 0.005-inch thick mylar tape, 1/2-inch wide, 3/16-inch lap, right-hand lay. Printed circuit identification on each tape in black letters - 1 black, 2 white, 3 red, or 4 green.

Diameter over Nylon jacket, inch	0.265

Clear nylon jacket over separator tape. Thickness of nylon jacket-approximately 0.006 inch

Diameter over grouped shielded conductors, inch	0.640

Four shielded conductor pairs cabled with a 5-inch right-hand lay. Filler material consisted of a cream colored elastomeric compound, with a 0.102-inch diameter black rubberlike strand in the void between each shielded pair.

Diameter over binder tape, inch	0.670

Binder tape consisted of a black rubber impregnated cloth tape 0.011-inch thick x 1 1/2-inch wide, 1/2-inch lap, left-hand lay.

Manufacturer's Identification Tape: Cream colored tape located under binder tape.

Diameter over inner jacket, inch	0.825

Inner jacket consisted of a black rubberlike compound resembling butyl rubber.

Jacket thickness, inch	Max - 0.102
	Min - 0.087
	Avg - 0.094

Diameter over outer jacket, inch	0.955

Outer jacket consisted of a black rubberlike compound resembling arctic polychloroprene.

Jacket thickness, inch Max - 0.081
Min - 0.070
Avg - 0.078

Printing on outer jacket in white letters 1/8-inch high, EBDS-2SWU-4-MOD

NOTE: There was no adhesion between the inner and outer jackets.

3. TYPE EBDS-THOF-3-MOD

Diameter over stranded conductor, inch	0.055

Conductor - 7 strands x 0.019-inch coated copper. Strand interstices filled with a black plastic compound.

Diameter over insulated conductor, inch	0.184

Insulation consisted of a black rubberlike compound resembling butyl rubber, avg. thickness, 0.065 inch

Circuit Identification - White printing on insulation, 1 black, 2 white, or 3 red

Diameter over Nylon jacket, inch	0.198

Clear nylon jacket over insulation, thickness approximately 0.007 inch

Diameter over grouped conductors, inch	0.378

Three conductors cabled with 2 1/2-inch left-hand lay. Filler compound consisted of a cream colored elastomeric compound.

Diameter over binder tape, inch	0.404

Binder tape consisted of a black rubber impregnated cloth tape, 0.010-inch thick x 15/16-inch wide, 1/4-inch lap, right-hand lay.

Manufacturer's Identification Tape: Cream colored tape located under binder tape.

Diameter over jacket, inch	0.635

Jacket consisted of a black rubberlike compound resembling arctic polychloroprene.

Jacket thickness, inch | Max - 0.140
Min - 0.085
Avg - 0.128

Printing on cable jacket in white letters 1/8-inch high, EBDS-THOF-3-MOD.

4. TYPE EBDS-THOF-42-MOD

Diameter over stranded conductor, inch 0.267

Conductor - 7 x 7, 49 strands, 0.0295-inch coated copper. Strand interstices filled with a black plastic compound.

Diameter over insulated conductor, inch 0.393

Insulation consisted of a black rubberlike compound resembling butyl rubber, average thickness, 0.063 inch

Circuit Identification - White printing on insulation, 1 black, 2 white, or 3 red

Diameter over Nylon jacket, inch 0.421

Clear nylon jacket over insulation. Thickness of jacket, approx. 0.014 inch

Diameter over grouped conductors, inch 0.876

Three conductors cabled with 8-inch, left-hand lay. Filler material consisted of a cream colored elastomeric compound, with a 0.205-inch diameter black rubberlike strand in the void between each conductor.

Diameter over binder tape, inch 0.900

Binder tape consisted of a black rubber impregnated cloth tape, 0.010-inch thick x 2-inch wide, 11/16-inch lap, right-hand lay

Manufacturer's Identification Tape: Cream colored tape located under binder tape.

Diameter over jacket, inch 1.270

Jacket consisted of a black rubberlike compound resembling arctic polychloroprene

Jacket thickness, inch	Max - 0.203
	Min - 0.152
	Avg - 0.178

Printing on cable jacket in white letters, 1/8-inch high, EBDS-THOF-42-MOD.

5. TYPE EBDS-MWF-24-MOD

Diameter over stranded conductor, inch	0.049

Conductor - 7 strands x 0.016-inch coated copper. Strand interstices filled with a black plastic compound.

Diameter over insulated conductor, inch	0.114

Insulation consisted of a black rubberlike compound resembling butyl rubber, average thickness, 0.032 inch, an oily substance was found on outer surface of insulation.

Circuit Identification: White printing on insulation, 1 black, 2 white, 3 red, etc on 24 conductors.

Diameter over Nylon jacket, inch	0.122

Nylon consisted of a clear coating of nylon, approx. 0.004 inch

Diameter over grouped conductors, inch	0.685

Twenty-four conductors cabled with 13-inch right-hand lay. Filler compound consisted of a cream colored elastomeric compound.

Manufacturer's Identification Tape: Cream colored tape located under binder tape.

Diameter over binder tape, inch	0.708

Binder tape consisted of a black rubber impregnated cloth tape, 0.010-inch thick x 2-inch wide, 3/4-inch lap, right-hand lay

Diameter over jacket, inch	1.025

Jacket consisted of a black rubberlike compound resembling arctic polychloroprene.

Jacket thickness, inch	Max - 0.175
	Min - 0.145
	Avg - 0.160

Table I7-2

Tensile Strength of Jacket Compounds Subjected to 58 Days of Immersion in Pressure Compensating Fluids

"As Received"

	Jacket Compound*				
	A	B	C	D	E
Tensile Strength, psi	1950	2110	1740	6010	2100
Elongation, %	370	350	410	720	320

	Fluid**	Percent Change After 58 Days of Immersion				
		A	B	C	D	E
Tensile Strength	L582	-13.8	-25.6	+39.6	-12.1	+24.8
	L597	-19.0	-27.5	+26.0	- 0.7	+34.2
	L574	- 4.1	- 4.7	+54.0	+ 1.0	+43.4
	L576	- 1.5	+11.4	+15.5	+ 8.1	+41.5
	L587	- 7.7	+ 3.3	+20.7	+ 1.0	+41.0
	L575	+ 1.5	+16.6	+12.6	+ 3.3	+ 4.8
Elongation	L582	-10.8	-25.7	-89.0	+ 0.7	-68.8
	L597	-17.6	-27.2	-42.7	- 6.2	-78.0
	L574	- 6.7	- 8.6	-91.0	- 6.9	-92.0
	L576	0	+ 2.9	-36.6	-11.1	-87.5
	L587	- 6.7	- 4.3	-56.1	-16.7	-92.0
	L575	- 6.7	+ 5.7	-19.5	- 4.2	-18.8

*A - Arctic Neoprene (NR-1)
B - Arctic Neoprene (Standard Navy MWF-24)
C - Vinyl
D - Polyurethane
E - Nitrite Rubber

**L582 - MIL-H-5606B (Petroleum Base)
L597 - VVI-530 (Transformer Oil)
L574 - MIL-L-6081C (Type 1010 Petroleum Base)
L576 - MS-2110 TH (Hydraulic Fluid)
L587 - MIL-S-21568 (Silicone Fluid, 1 cs)
L575 - VVD - 001078 (Silicone Fluid, 10 cs)

Note: The above results are the average of five specimens for each condition.

Table I7-3
Proposed Tentative List of Cables for Deep Submergence Applications

Power Cables - 600 Volts

AWG Size	Circular MIL Area	Ampacity (approx.) 50° C Ambient			
		1-CDR	2-CDR	3-CDR	4-CDR
14	4107	25	20	18	15
10	10380	40	35	32	28
8	16510	60	50	45	40
6	26250	75	65	58	52
4	41740	110	95	85	75
2	66370	150	130	115	100
0	105500	220	190	170	140
00	133000	260	230	200	170
000	167800	300	280	240	-

AWG Size	Estimated Cable Weight and Size W= Weight, Lb./Ft. - D= Diameter, Inches							
	1-CDR		2-CDR		3-CDR		4-CDR	
	W	D	W	D	W	D	W	D
14	0.03	0.25	0.12	0.46	0.15	0.48	0.19	0.56
10	0.07	0.32	0.21	0.60	0.26	0.65	0.35	0.71
8	0.11	0.39	0.36	0.72	0.40	0.79	0.49	0.84
6	0.16	0.48	0.53	0.91	0.61	0.97	0.71	1.02
4	0.25	0.56	0.82	1.1	0.96	1.22	1.2	1.28
2	0.36	0.64	1.2	1.3	1.3	1.43	1.45	1.50
0	0.53	0.75	1.46	1.6	1.8	1.69	2.16	1.81
00	0.66	0.83	1.67	1.8	2.16	1.86	2.70	2.10
000	0.83	0.92	1.88	1.95	2.60	2.05	-	-

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Table I7-3 (Continued)

Control Cables - 600 Volts				
Number of Conductors*	Configuration	Ampacity ind/aug (approx)	Diameter in. (approx)	Weight lb/ft (approx)
7	1-6	9/6	0.50	0.16
10	2-8	9/6	0.64	0.23
14	4-10	9/6	0.64	0.28
19	1-6-12	9/5	0.75	0.36
24	2-8-14	9/5	0.84	0.48

*AWG #16 (2583 circular mils)

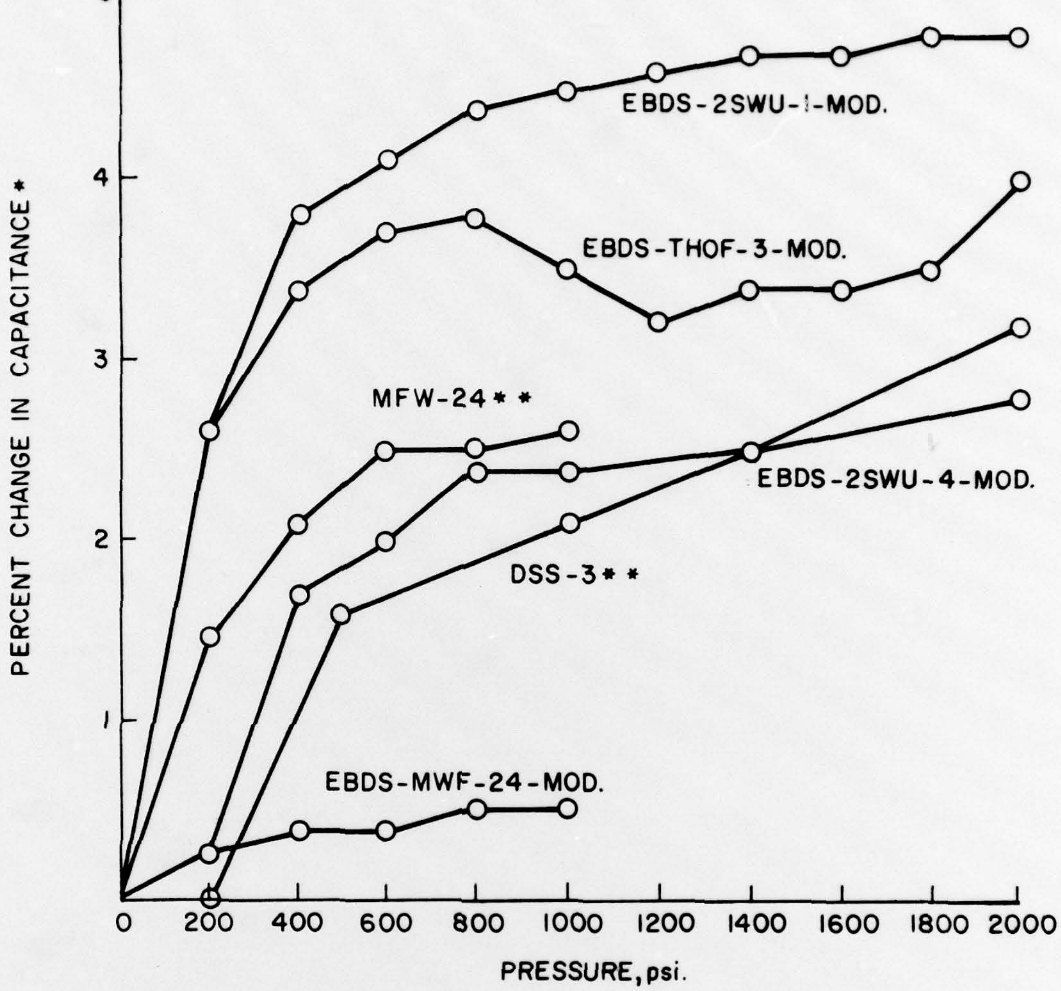
Shielded Cables - 600 Volts					
Conductor AWG Size	Circular MIL Area	Number of Conductors			
		2	3	4	7
18	1624	√	√	√	√
16	2583	√	√	√	—
14	4107	√	√	√	—

AWG Size	Estimated Cable Weight and Size W = Weight, lb/ft — D = Diameter, inches							
	2-CDR		3-CDR		4-CDR		7-CDR	
	W	D	W	D	W	D	W	D
18	0.12	0.39	0.16	0.45	0.18	0.50	0.25	0.62
16	0.16	0.50	0.18	0.50	0.20	0.55	—	—
14	0.18	0.50	0.20	0.50	0.24	0.62	—	—

Shielded Pair Cables

Number of Shielded Pairs	Diameter in. (approx)	Weight lb/ft (approx)
1	0.40	0.15
3	0.62	0.25
7	0.81	0.4
12	0.95	0.6
19	1.0	0.7

Conductors — AWG #18 (1288 cm)



*INDIV. CONDUCTORS TO OTHERS & WATER
** STANDARD NAVY TYPE CABLE

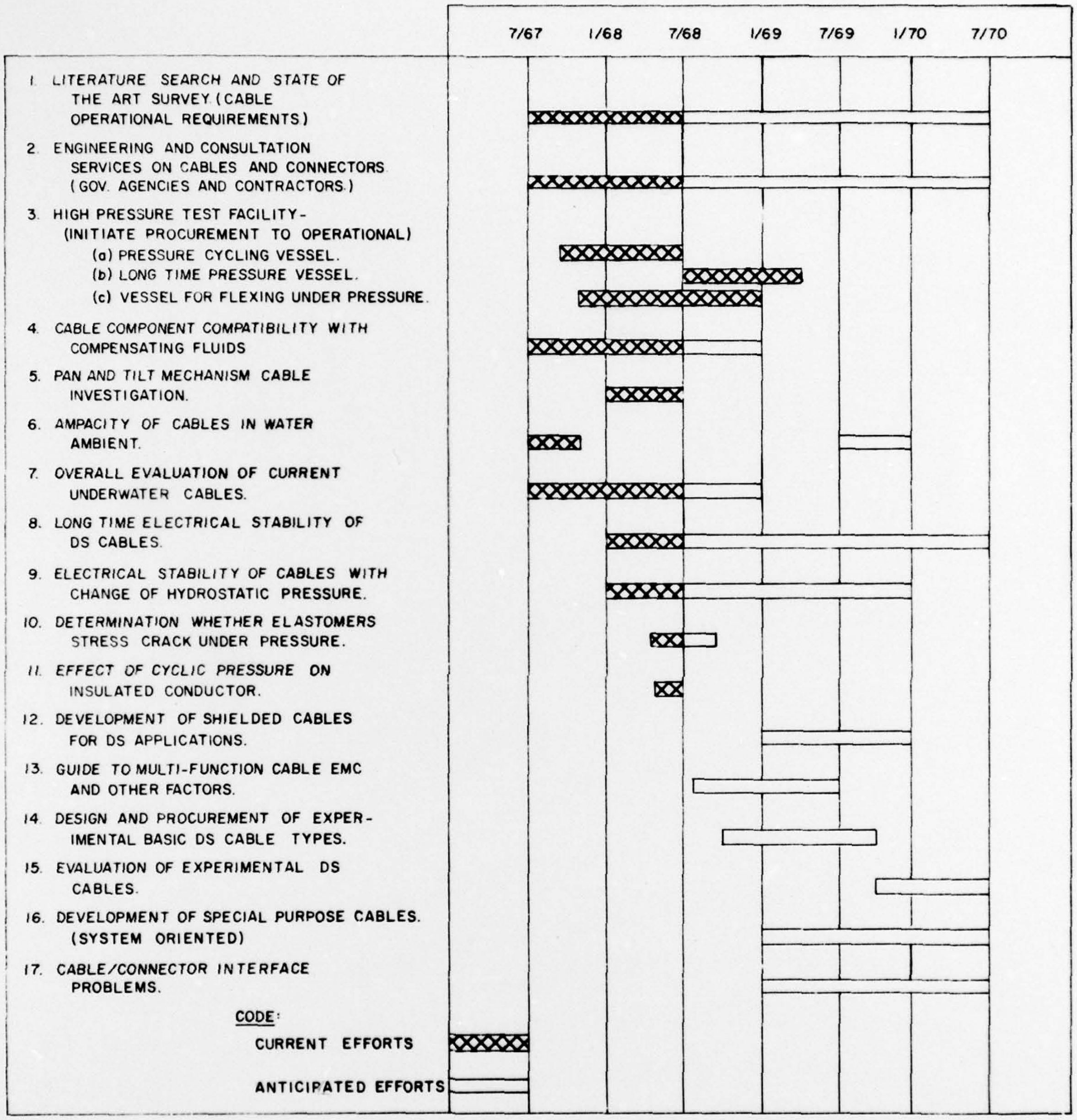
Figure I7-1

Capacitance Change vs External Hydrostatic Pressure

Annex II-7

Status

Underwater Electric Cable for Deep Submergence Applications


7/67
1/68
7/68
1/69
7/69
1/70
7/70
1. LITERATURE SEARCH AND STATE OF THE ART SURVEY (CABLE OPERATIONAL REQUIREMENTS)
2. ENGINEERING AND CONSULTATION SERVICES ON CABLES AND CONNECTORS (GOV. AGENCIES AND CONTRACTORS.)
3. HIGH PRESSURE TEST FACILITY- (INITIATE PROCUREMENT TO OPERATIONAL)
(a) PRESSURE CYCLING VESSEL.
(b) LONG TIME PRESSURE VESSEL.
(c) VESSEL FOR FLEXING UNDER PRESSURE.
4. CABLE COMPONENT COMPATIBILITY WITH COMPENSATING FLUIDS
5. PAN AND TILT MECHANISM CABLE INVESTIGATION.
6. AMPACITY OF CABLES IN WATER AMBIENT.
7. OVERALL EVALUATION OF CURRENT UNDERWATER CABLES.
8. LONG TIME ELECTRICAL STABILITY OF DS CABLES.
9. ELECTRICAL STABILITY OF CABLES WITH CHANGE OF HYDROSTATIC PRESSURE.
10. DETERMINATION WHETHER ELASTOMERS STRESS CRACK UNDER PRESSURE.
11. EFFECT OF CYCLIC PRESSURE ON INSULATED CONDUCTOR.
12. DEVELOPMENT OF SHIELDED CABLES FOR DS APPLICATIONS.
13. GUIDE TO MULTI-FUNCTION CABLE EMC AND OTHER FACTORS.
14. DESIGN AND PROCUREMENT OF EXPERIMENTAL BASIC DS CABLE TYPES.
15. EVALUATION OF EXPERIMENTAL DS CABLES.
16. DEVELOPMENT OF SPECIAL PURPOSE CABLES. (SYSTEM ORIENTED)
17. CABLE/CONNECTOR INTERFACE PROBLEMS.
CODE:
CURRENT EFFORTS
ANTICIPATED EFFORTS

Enclosure (8)

MAY 1968 STATUS REPORT
DOT TANDEM PROPULSION SYSTEMS
TASK AREA S4728 TASK 12320
WITH ANNEX I-8

Ref: (a) NAVSHIPRANDCEN ltr NP/9440 (M710 ARS) of 11 Aug 1967
(b) NAVSHIPS ltr 9410 Ser 6141-215 of 15 Sep 1967
(c) NAVSEC ltr 9440 Ser 6144-330 of 18 Jan 1968
(d) MEL Rept 32/68 of 13 Feb 1968
(e) "Tandem Propulsion Machinery," Sperry Rand Corporation, ANNADIV NSRDC sponsored Rept 140/68 of Apr 1968

Encl: (1) Sketch - Tandem Propulsion System Vehicle Configuration

1. Introduction. Reference (a) proposed a program for the investigation of the Tandem Propulsion System (TPS). The program was approved with minor modifications and a reduced funding level by reference (b). Guidelines for the program relative to vehicle missions, performance requirements and general physical characteristics were provided by reference (c). The initial quarterly progress report on the investigation, covering the period of September through December 1967, was submitted as reference (d). The progress made during the period January through April 1968 follows.

2. Status of Investigation. Four principal efforts are currently under way. These are:

- Hydrodynamics study - propeller forces (Phase I (a) of program). This is being carried out by NSRDC, Code 520.

- Stability and system simulation hydrodynamic studies (Phase I (b) of program). This is being carried out by NSRDC, Code 530.

- Survey and preliminary engineering analysis of actuator system (part of Phase I (c) of program). This is being carried out by the Machinery Laboratory, ANNADIV NSRDC, Code A723.

- Requirements analysis and selection of TPS design parameters (part of Phase I (c) of program). This is being carried out by Sperry Systems Management Division of Sperry Rand Corporation.

The progress made and the results thus far obtained are described in the following paragraphs.

Hydrodynamics Study. The objective of this effort is to determine the forces and moments on individual blades of the tandem propellers. This will define the external load cycle experienced by blade spindles and mechanisms. The blade forces will be

measured through the use of a recently developed dynamometer mounted in an appropriate streamlined body. The experimentally determined forces will be compared with predictions made using the best available quasi-steady methods in order to establish applicable methods for predicting performance and side motion capabilities of a cyclic pitch propeller system.

Thirty percent of the originally-requested funds for FY 1968 have been provided for this effort. While initiation of this phase was not scheduled to start until May, 1968, reference (b), it was actually started earlier and has been underway during the period reported herein. Efforts are currently underway to advance the scheduled April 1969 completion date.

Conclusions arrived at thus far in the initial considerations of this study follow:

- The blade lift rather than the blade drag will normally be the dominating side thrust vector.

- The position of the blade spindle axis rather than the slope of the adjacent hull and hub will normally determine the direction of the blade thrust vector. Relative angles between the spindle and hull of 90° to 75° are hydrodynamically acceptable. However, the lesser angle may cause complications in the dynamometer installation.

- Since the blade spindle axis does not need to be perpendicular to the hull, the use of hull slopes that do not allow spindle/hull slope angles approaching 90° should be acceptable from machinery design considerations.

- There is no reason to believe that spindle axis angles other than 90° to the hull (within reasonable limits) will produce an excessive and detrimental blade-wake wash against the hull.

- The use of a relatively large number of blades, e. g. twelve, can cause proximity interference effects that would be evident during side thrusting.

- The blade spindle dynamometer recently developed which will be applied to this investigation will allow precision force measurements that will enhance the confidence that may be placed in the predictive analytical procedures. This may make it practicable to employ advanced materials for the blades, e. g. rubber, plastic or fiberglass, and to use lightweight cycling mechanisms.

Stability and System Simulation Hydrodynamic Studies. The objective of this effort is to determine the stability and controllability aspects of a TPS-equipped vehicle. This will be accomplished through the application of the standard procedures used for indicating the stability and controllability of tactical submarines. It should be noted that these procedures provide sufficient design confidence to allow going from a model directly to a full-scale submarine, provided all refinements are included.

Twenty percent of the originally-requested funds for FY 1968 have been provided for this effort. While initiation of this phase was not scheduled to start until May 1968, per reference (b), it was actually started earlier and has been underway during the period reported herein. Efforts are currently underway to advance the April 1969 completion date.

A double-ended configuration, symmetrical except for a possible shroud stabilizer at the stern, per annex I-8 has been decided on for the TPS vehicle of this investigation. The following advantages of this configuration were considered very attractive:

- It allows comparison with the DSRV.
- It will have significantly less resistance than the DSRV, in both the ahead and the astern motion.
- Duplicate machinery can be used with resulting better maintainability and logistics factors.
- Construction of the model for the hydrodynamic tests is simplified, since the fore and aft propellers and driving machinery are identical and the hull has fore-and-aft symmetry.
- Astern controllability is expected to be improved over that of the DSRV.
- Maneuvering versatility may possibly be increased.
- The fine nose gives better bow-propeller efficiency.
- The vehicle can be readily evaluated with or without shroud stabilizers.
- Relatively little extension work would be required to orient this configuration to foreseen vehicles.
- It is more economical to evaluate this configuration than to initiate the investigation with DSRV-shaped hull, with later extension to an entirely different hull.

Agreed-on design parameters are as follows:

- The propeller diameter will not exceed the maximum hull diameter.
- The hub diameter will be in the range of 40-60 percent of the maximum hull diameter.
- Rake angle is tentatively 35°, although this is subject to change.
- Hull slope will be approximately 17° near the propeller.

A previous investigation by NSRDC has already shown that a basic TPS vehicle is not stable and that some type of stabilizer will be required. The problem is to develop a stabilizer concept that will provide adequate stability and controllability and yet not unduly degrade the performance and effectiveness of the TPS. This will be explored in model tests. One design considered is that of a retractable ring-shaped stabilizer mounted behind the stern propeller, as conceived by Mr. Morton Gertler, NSRDC.

Survey and Preliminary Engineering Analysis of Actuator System. The objective of this effort is to examine the state-of- the-art as regards submersible actuators, to access the feasibility of their application to TPS, and to identify the problem areas and development needs relating to them.

More than thirty manufacturers of hydraulic actuators have been queried relative to the use of their equipment under submerged conditions. While several indicated that they had supplied hydraulic actuators for use on submersible vehicles, no information was available pertaining to the service performance.

The principal problem area appears to be the contamination of the hydraulic fluid when the shaft is withdrawn into the oil-filled actuator housing after having been extended into the sea-water environment. Possible measures to minimize or prevent the contamination or its effects include the following:

- Use of a water-miscible hydraulic fluid.
- Use of special finishes or surface coatings on the shafts.
- Use of special sealing techniques, such as the incorporation of bellows.

A report on this study is in preparation and will be submitted in the near future.

Requirements Analysis and Selection of TPS Design Parameters. This is Task A-1 of a group of work assignments being contracted to the Sperry Systems Management Division of Sperry Rand Corporation. The other tasks in this program are described briefly in the following paragraphs. Task A-1 covers the following:

- A requirements analysis for TPS machinery components based on missions, physical characteristics, thrust, controllability, structure impact requirements, reliability and maintainability goals. Design constraints, performance requirements and such parameters as propeller size and blade conical path angle will be defined.
- An examination of structural and vibration loads.
- Propeller rotational drive design studies.

The contract for Task A-1, in the amount of $24,933 was awarded on 29 February 1968. An interim report of progress was submitted as reference (e). This report outlined the results of initial studies made by Sperry on material requirements, design considerations, stress and weight analyses. The final report on this task is scheduled for issuance about 10 June 1968.

Task A-2 of the Sperry program involves a determination of TPS internal design parameters. It will cover the following:

- Study and design of the blade control mechanism, as based on blade wave slap and impact loads, blade dynamic torque and force characteristics, and vehicle thrust and controllability requirements.

- A reliability prediction using MIL-STD-756A as a guide. This will be the basis for a maintainability analysis.

- A windage and friction loss analysis.

- A weight and displacement analysis.

A contract for Task A-2 in the amount of $24,993 was awarded 26 April 1968. Completion of the task is scheduled within three months.

Task A-3 of the Sperry program covers the preparation of assembly layout drawings and a summary analysis report. This will be based on the machinery studies made under Tasks A-1 and A-2. A contract for this task is presently being negotiated with Sperry. It is expected that the work will require about three months for completion after award of the contract.

Task B-1-1 of the Sperry program covers a determination of the design elements to be tested and the development of a test plan. It will include the following:

- Use of design studies and mathematical analyses to explore various component design concepts.

- A selection of component designs for test on the basis of trade-offs of functional adequacy, reliability and maintainability considerations.

- Development of a test program plan to include procedures for reporting reliability analysis, test results, and design reviews.

A contract for this task is presently being negotiated with Sperry. It is expected that the work will require about 2-1/2 months after award of contract.

Task B-1-2 will cover the design of components and unique test equipment for proof tests. It is expected that this work will require about three months, but the detailed content of the task has not yet been defined.

3. Milestone Status. The following FY 1968 milestones have been completed.

a. September 1967. Program authorized and funded (completed September 1967).

b. October 1967. Program guidelines (vehicle configuration, performance requirements, etc.) provided by NAVSEC (completed January 1968).

c. May 1968. Start Phase I (a), Tandem propeller hydrodynamics study - propeller forces (started April 1968).

d. May 1968. Start Phase I (b), Stability and system simulation hydrodynamics studies (started April 1968).

The following FY 1968 milestones have been combined essentially in the contracting arrangements with Sperry and the work involved is underway.

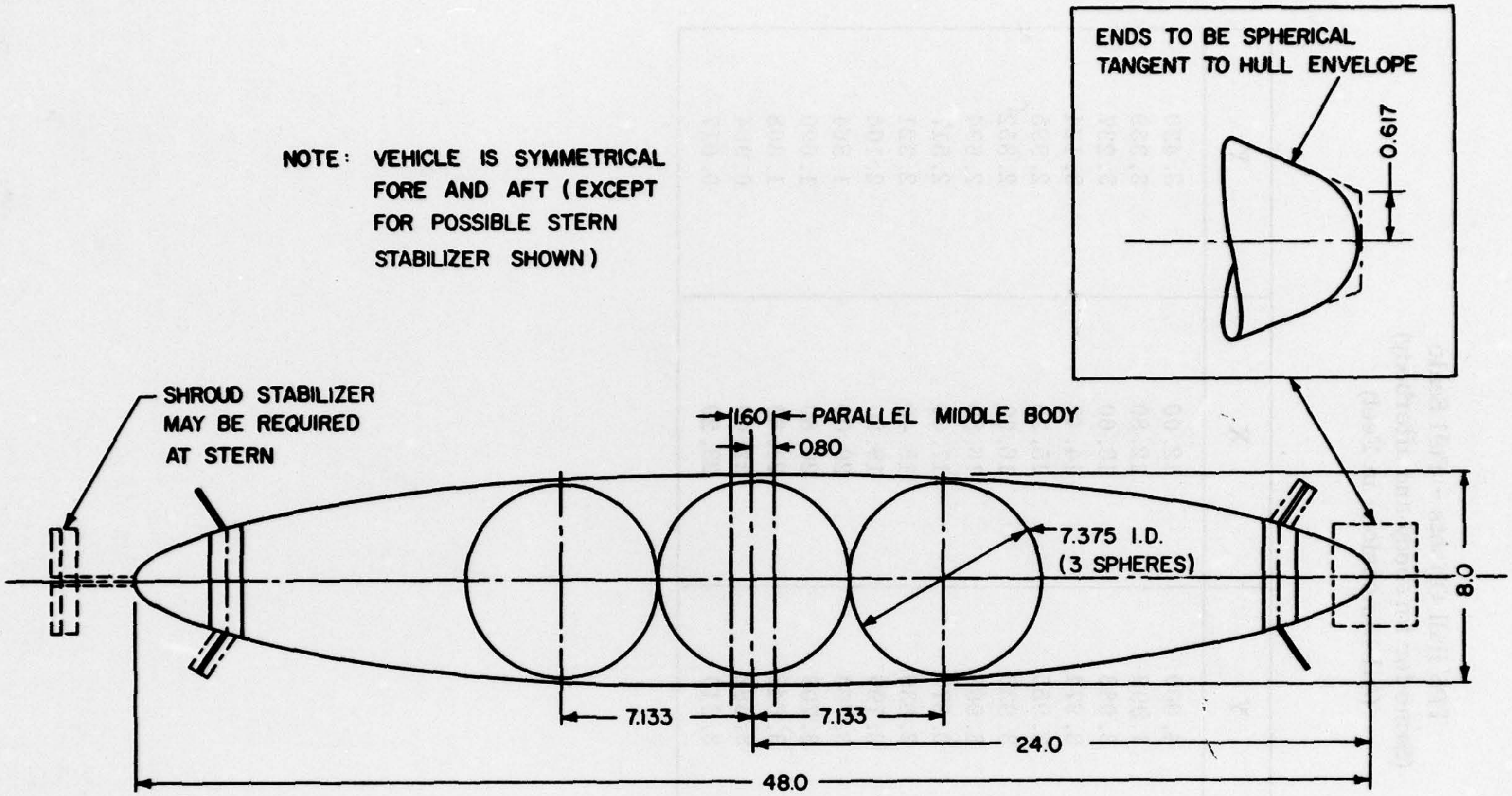
e. October 1967. Initiate procurement activities for Design Contract A (preliminary engineering design).

f. January 1968. Start Phase I (c), Machinery component study and development program.

g. April 1968. Report on preliminary propeller design. (Report 140/68 of 25 April 1968 was submitted in partial fulfillment of this milestone).

Annex I-8

Tandem Propulsion System



ALL DIMENSIONS ARE IN FEET

SKETCH OF PROPOSAL TANDEM PROPELLER VEHICLE SHOWING PRINCIPAL DIMENSIONS OF OUTER HULL AND PRESSURE HULL

(PROPELLERS AND SHROUD STABILIZER ARE SHOWN SCHEMATICALLY)

TPS Hull Offsets - Full Scale
(Same for forebody and afterbody)
(All Dimensions in Feet)

X	Y	X	Y
0	4.000	12.00	3.430
0.80	3.998	12.80	3.339
1.60	3.988	13.60	3.237
2.40	3.974	14.40	3.124
3.20	3.955	15.20	2.995
4.00	3.933	16.00	2.852
4.80	3.906	16.80	2.694
5.60	3.875	17.60	2.517
6.40	3.839	18.40	2.321
7.20	3.799	19.20	2.104
8.00	3.753	20.00	1.864
8.80	3.703	20.80	1.600
9.60	3.646	21.60	1.308
10.40	3.582	22.40	0.984
11.20	3.510	23.20	0.617